LIGHT THE DOMINANT FORCE OF THE UNIVERSE.

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LIGHT THE DOMINANT FORCE OF THE UNIVERSE:

SHOWING

BY MEANS OF EXPERIMENTS

WHAT LIGHT IS; WHAT ELECTRICITY IS; AND WHAT LIFE IS:

ALSO

HOW TO RECONCILE RELIGION AND SCIENCE.

BY

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PREFACE.

WE find Davy at the beginning of the present century pointing out in his "Essays on Heat, Light, and the Combinations of Light" that "bodies exist in different states, and these states depend on the differences of the action of the attraction and of the repulsive power on their corpuscles." Also that "when the attraction predominates over the repulsive motion, the body exists in the state of solidity. . . . When the attraction and repulsion are in equilibrio the body exists in the state of fluidity. . . . And when the repulsive motion predominates over the attraction the body exists in the state of gazity."

In his "Chemical Philosophy," we find him stating, at p. 80, that "heat or the power of repulsion may be considered as the antagonist power to the attraction of cohesion, the one tending to separate, the other to unite the parts of bodies; and the forms of bodies depend upon their respective agencies."

At p. 69 he states that "for anything we know to

the contrary, gravitation and cohesion may be mere modifications of the same general power of attraction, in the one case acting at distances that can easily be measured, and in the other case operating at distances which it is difficult to estimate."

Again, at p. 57, he says that "the laws of crystallization, of definite proportion, and of the electric polarities of bodies seem intimately related; and the complete illustration of their connexion probably will constitute the mature age of chemistry."

At p. 178 we find him noticing that in the Electric Light platinum melted more readily at the positive than at the negative pole, and that there was a difference in appearance between the carbon point at the positive, and that at the negative pole.

Also about the same time we find Dalton pointing out in his "New System of Chemical Philosophy," that "all bodies of sensible magnitude, whether liquid or solid, are constituted of a vast number of extremely small particles or atoms of matter bound together by a force of attraction . . . . besides the force of attraction . . . . we find another force that is likewise universal, or acts upon all matter which comes under our cognizance, namely, a force of repulsion . . . . ascribed to the agency of heat."

And at p. 144 he speaks of the "great antagonist powers of attraction and repulsion."

Now Davy thought that Light was a body, and

as such could enter into chemical combination with oxygen, and form a compound of light and oxygen, to which he gave the name of Phosoxygen.

And Dalton thought that heat was a "subtle fluid."

And so thinking, neither Davy nor Dalton could get any farther.

But what I wish now to point out is how very little, in spite of all our advantages, we have advanced beyond the point reached by Davy and Dalton in our knowledge of the relations subsisting between force and matter, or of the nature of the action by which time after time crystals are formed with the greatest precision, or of the nature of the Electric Light, or of that of an electric current. That the case is so, see Prof. Tyndall still explaining the formation of crystals, by polar forces (Tyndall "On Light," p. 101), or in precisely the same way in which Davy endeavoured to explain it. Or listen to Dr. Spottiswoode, President of the Royal Society, in a lecture before the British Association at York, on the 5th September, 1881, stating that "We know, it is true, how to produce electricity or electrical action as well as how to transmit it, by means of wires to a distance . . . . But we know neither what electricity really is, nor the process whereby it is transmitted."—*Nature,* Oct. 6, 1881, p. 546.

I am going to try and show that if with our present advantages we are content to go back once

more to the source, and go over the course again, verifying Davy's work and narrowly examining the whole of the channel, we shall find that not only was Davy right in his statement that heat or the power of repulsion is the antagonist power to the attraction of cohesion; but right also in his conjecture that gravitation and cohesion are mere modifications of the same general power of attraction. And then with the help of Newton's discoveries that gravity operates between the heavenly bodies as well as upon the earth; and that for every action there is always an equal and contrary reaction; and with the help of the numerous other discoveries since made, looking to the principles which underlie the laws which have been established in the various branches of natural science rather than to the mere letter, we shall find a little in advance of the point where Davy stopped, another channel, which, in our eagerness to push forward, we before overlooked, and which indeed is the main channel leading straight to the great ocean of truth; where we shall be able to push out in any direction we may choose; and where we shall be able not only to understand the way in which a crystal is formed, and the nature of the Electric Light or of an electric current, but shall be able also to look into the mysteries of the great question of Life which concerns us all so closely.

I have referred at paragraph 103 to the principle of the Lever, but have omitted to discuss the other mechanical principles, which do not bear directly upon the general question. I might, however, with advantage have pointed out that the fact that with Gravity, Light, Heat, and Electrical and Magnetic force the intensity diminishes as the square of the distance indicates very clearly in all a centripetal or centrifugal action; as is admirably shown in the case of Light, in Miller's "Chemistry," part i., p. 166, by taking the case of a luminous point emitting continuously a steady light, and supposing it to be placed successively at the centres of several hollow spheres of different diameter. When, it will be apparent that though the inner surfaces of the spheres all receive absolutely the same quantity of light, that quantity of light is, since the surfaces of spheres are to each other as the squares of their radii, distributed over four times as large an area when the diameter of the sphere is four feet, as it is when the diameter of the sphere is only two feet, and therefore that the intensity at every point on the inner surface of the sphere four feet in diameter, can only be one-fourth of the intensity at every point on the inner surface of the sphere two feet in diameter. At the same time it will be apparent that the luminous point which is one foot distant from every point of the inner surface in a sphere two feet in

diameter, is only two feet, or twice as far away from every point of the inner surface of a sphere four feet in diameter.

In connexion with the chapter on Physiology it may be well to notice that Aristotle held (see Grote's "Aristotle," p. 463) that in addition to minor varieties, there were two great varieties of soul in contradistinction to matter, viz. the Nutritive soul, common to plants and animals alike, and the primary cause of digestion and nutrition, and the Sentient soul, communicated by the male parent in the act of generation, and confined solely to animals. Also that (p. 476) he considered memory to be "a movement proceeding from the centres and organs of sense to the soul, and stamping an impression thereupon; whilst reminiscence is a counter-movement proceeding from the soul to the organs of sense."

In regard to the explanation in the concluding Chapter, it is necessary to point out that the general idea therein developed originated with Sir Isaac Newton, whom we find stating in his third letter to Dr. Bentley, that "gravity must be caused by an *agent* acting constantly according to certain laws; but whether this *agent* be material or immaterial I have left to the consideration of my readers;" after having in his second letter stated that "the Motions which the Planets now have could not

spring from any natural cause alone, but were impressed by an intelligent *agent.*" In his fourth letter he says explicitly that in his opinion this intelligent *agent* is a Divine agent. The same idea we find adopted by Sir J. Herschel, who says, in "Outlines of Astronomy," that it is but reasonable to regard gravity "as the direct or indirect result of a *consciousness* and a *will* existing somewhere."

In conclusion, I would add that I have endeavoured to work out the whole argument by experiment, avoiding all technicalities, and advancing step by step from first principles in such a way that the whole statement may be intelligible to the non-scientific reader.

I am fully conscious of the clumsiness of the arrangement in many parts, and of much in it that is defective, and of much that could be improved; but the two years' furlough which gave me leisure to put this statement, sketched out before in pamphlet form in India, into a practical shape, have now expired, and I can devote no more time for the present to the work, and must therefore leave it, being convinced that in spite of all its defects, it presents a complete chain connecting all branches of Natural Science, and one which, though some of its links may have to be replaced or strengthened, will stand the tests of time and rough usage.

October 23, 1882.

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LIGHT THE DOMINANT FORCE OF THE UNIVERSE.

CHAPTER I.

ERRATA.

Page 31, *line* 8, *for* "predominate" *read* "predominates."
Page 153, *line* 21, *for* "striking" *read* "stroking."

moons or satellites are, in the same way, coerced by the planets.

Whilst, on the earth, we find that the different masses of rock, clay, sand, water, air, &c., of which the earth is made up, are all held together and compelled to keep their proper positions by the action of an attractive force which we call gravity.

B

Then, from the sciences of chemistry and physics we learn that the masses about us of rock, clay, sand, water, air, &c., and everything in them, whether animate or inanimate, cognizable by our senses, are none of them continuous masses; but every one of them consists of an aggregation of exceedingly minute separate bodies or particles, of one or more out of some sixty or seventy different kinds, arranged singly if the mass consists of elementary substances (i.e. substances composed entirely of particles of one kind), or in groups if the mass is made up of compound substances (i.e. substances composed of particles of more than one kind, combined together in groups, in such a way, that, in the same substance, each group contains the same number of particles and the same proportion of each of the several kinds of particles in the substance, arranged in the same way, as every other group in that substance contains). Also we learn that, in such of these masses as are solids, the particles or groups of particles of which each mass is made up, are bound together, particle to particle or group to group, by cohesive force. And further, we learn that, in compound substances, the particles in each of the groups of particles of which the substances are made up, are bound together particle to particle so firmly, by chemical force, that they do not separate, even when the groups are separated from each other and dis-

persed hither and thither by the conversion of the substances from the solid into the gaseous state.

The science of electricity, too, teaches us that by operating in different ways—with magnets, batteries, or electric machines—upon the substances of which the masses of matter on the earth are made up, so as to effect changes in the arrangement of the particles, or in the way they are combined together, or in the forces by which the particles are held together, in those masses, it is possible to disengage from the masses force currents manifesting, in a marked degree, the action of attractive force.

2. On the other hand, there is, to a similar extent, everywhere about us, evidence of the presence and action of a repulsive force pervading all space and everywhere resisting and opposing, though everywhere held in subjection by the dominant compulsive force.

For we find, in the heavens, that both the planets and the satellites, under the influence of a centrifugal repulsive force, ceaselessly strive to escape from the thraldom of the centripetal attractive force by which they are held, and to disperse in space.

Whilst, on the earth, the particles of which, as we have seen, every mass of matter is made up, are kept apart, particle from particle and group from group, by an expansive force; so that every mass of matter, whether in the solid, liquid, or gaseous

state, is able to offer, to a greater or less extent, resistance to the action of any force tending to compress it, or to drive its particles closer together Also, under the action of heat, mountains are sometimes shaken, or upheaved by earthquakes, streams of molten lava are poured forth from volcanoes, the surface water of seas is evaporated and raised high into the air to form clouds, solids are expanded and converted into liquids, and liquids into gases, and even the close association of particles, in the groups of particles of which compound substances are made up, is put an end to.

Further, the currents, which, as we have seen, the electrician is able to disengage from masses of matter, manifest, under certain circumstances, a repulsive as well as an attractive action.

3. The aim, then, herein will be by investigating the modes of action and of transference of the forces, which we thus recognize as acting in the universe, to show, in the first place, that the chemical force by which particles are collected and bound together to form the groups of particles of which compound substances are made up, is both the same force as the cohesive force by which particles, or groups of particles, are collected and bound together to form crystals, or solid masses of other forms; and also the same force as that of gravity, by which masses of matter are collected and bound together to form

the heavenly bodies; the difference in each case being one of degree only, due to the action taking effect at a shorter or at a greater distance, and not one of kind. Also that the process by which particles are brought together and arranged in regular order in the formation of one of the groups of particles of which compound substances are made up, is a representation, on a small scale, of the process by which groups of particles are brought together and arranged in order in the formation of any one of the many beautifully regular crystalline forms with which we are acquainted; and also, and even in a still more exact way, is a representation in miniature of the process by which masses of matter were once brought together and arranged in order in the formation of the heavenly bodies. And thus, in fact, to show that there is acting throughout the universe a single dominant compulsive force, which holding, so to speak, in its grasp each particle, each mass of matter, and each of the heavenly bodies, and able, when it receives accessions of strength, to tighten its grasp upon particle, mass, or body, and at any time to use any particle, mass, or body in its grasp, as a centre from which to act upon other particles, masses, or bodies, draws the particles together into groups, the groups into masses, the masses into heavenly bodies, and the heavenly bodies themselves about the source or the centres from which it

emanates or acts; thus connecting all together, and introducing everywhere law and order.

Similarly, to show in the same way that, whether known to us under the name of Centrifugal force, or of Heat, or of Positive Electricity, there is acting throughout the universe, side by side with this dominant compulsive force, a single repulsive force, which attaching itself to each particle, each mass of matter, and each of the heavenly bodies, and able when it receives accessions of strength to act with increased effort upon particle, mass, or body, and able also at any time to make use of any particle, mass, or body to which it has attached itself as a centre from which to act upon contiguous particles, masses, or bodies, constantly opposes and resists the action of the dominant compulsive force, and strives to drive the heavenly bodies far away from the source or centres about which they have been collected by compulsive force, to separate and scatter in every direction both the masses of matter of which the heavenly bodies are made up, and the particles of which the masses of matter are made up, and generally to wrench the bodies, masses, and particles from the grasp of the dominant compulsive force.

Thus a constant struggle goes on between the repulsive force and the dominant compulsive force, as the one force or the other receives accessions of strength, or whenever particles, masses, or bodies

specially favour the action of one of the forces in particular. But though the repulsive force sometimes so far succeeds in its opposition to the compulsive force, as to be able to break up masses of matter, and scatter the particles of which those masses are made up, it is never able absolutely to detach from the particles the hold of the compulsive force. Neither, on the other hand, is the dominant compulsive force ever able absolutely to oust the repulsive force from its hold upon any particle. But the two forces act everywhere side by side on every particle, mass, or body, sometimes with greater and sometimes with less effect, with the result of introducing everywhere symmetry, and at the same time infinite variety.

4. In the second place an endeavour will be made to show that it is to the struggle which on every side goes on between the two forces of compulsion and repulsion, by which the efforts of the one force or the other to tighten its hold on some particle, mass, or body, are made good with the effect of dislodging a portion of the other force, or are repelled or reflected; and to the varying turns the fight takes as force dislodged or reflected from one side reinforces the direct action of that force on some other side, and acting thus, on that side with concentrated effort, dislodges in its turn a corresponding portion of the other force, that all the changes which go on around us, and all power of doing or suffering, and

all sensations, and amongst others those of light and heat, are due.

5. The idea, then, in regard to light and heat, which will be presented for adoption, is that, on the one hand, the sensation of light is produced by the direct compulsive or dragging action upon the retina and optic nerve of the eye of impulses or efforts of compulsive force, tending to tighten the grasp of compulsive force upon the eye.

Whilst the sensation of heat, on the other hand, is produced by the direct repulsive or expansive action upon the sensor nerves scattered over the body of impulses of repulsive force.

In this way light will be shown to be directly connected with the dominant compulsive force acting throughout the universe, whilst heat will be shown to be directly connected with the repulsive force which throughout the universe acts in opposition to the dominant compulsive force.

6. We have seen that compulsive force holds in its grasp and connects together every particle, every mass of matter, and every one of the heavenly bodies in the universe, and that impulses of compulsive force are propagated from particle to particle; and yet that compulsive force is so stoutly resisted, and so closely beset at every particle by repulsive force, that no impulse or accession of compulsive force can pass from one particle to another without displacing

to an extent proportionate to the strength of the impulse, repulsive force. Hence, in passing through any mass of matter an impulse of compulsive force must not only force for itself a passage at every particle by displacing repulsive force, but it must also deviate from a straight path at every particle in order to get round the obstacle which an interval occupied by repulsive force offers, even when a sufficient amount of repulsive force to give passage to the impulse has been displaced, to the direct or straight passage of an impulse of compulsive force from particle to particle. Thus, although the general direction in which an impulse of compulsive force travels through any mass of matter may be straight, the path of the impulse must always be a wavy one; and, besides, since an impulse can only travel when it is in sufficient strength to force a passage, the movement by which an impulse is propagated must often be a spasmodic or intermittent one.

Hence the impulses of compulsive force, which produce in the eye the sensation of light, must always travel to the eye by a wave motion, whether minor waves are compounded together to form larger undulations or no.

For a like reason impulses of repulsive force must travel by a wave motion.

7. With this view in regard to the nature of light, it is seen that light is propagated by an emission as

Sir Isaac Newton taught; though it is propagated by an emission of force impulses and not by one of minute projectiles, as Newton thought.

It is also seen that light, as the advocates of the undulatory theory say, is propagated by undulations, though it is propagated by an undulatory movement in an everywhere active force medium, and not, as the advocates of the undulatory theory say, by the impact of undulations set up in a luminiferous ether, a medium invented for the purpose of transmitting undulations, and useless for any other; one too unrecognized by chemistry, and considered, as Professor Tyndall tells us in his book on Light, p. 49, by Sir David Brewster as a contrivance too clumsy for the Creator to be guilty of it.

8. We purpose, then, first to proceed to the consideration of the nature, action, and distribution of force in general, and afterwards to consider force separately in its relation to the sciences of chemistry, electricity, physics, physiology, &c., and hope to be able to show first that force when considered generally naturally differentiates into force of two kinds, which in the absence of better names we may call compulsive and repulsive force, of which the function of the one kind is to attract and that of the other to repel; though except in the oppositeness of their aim or action the two kinds are in all respects absolutely alike; just as the soldiers of two contend-

ing armies may be, except in the oppositeness of their aim, and that the one strive to compel and the others to repel, in all respects absolutely alike. We shall hope to show secondly in a review of some few of the facts taught by chemistry, not only more fully the existence and action of these two kinds of force, but also that the development of force of one or other or both of these two kinds is attended with emissions either of light or of heat or of both light and heat together. We shall then, in the third place, hope in the study of some of the facts demonstrated by electricity completely to establish a relation between light and compulsive force, and heat and repulsive force. Lastly, after showing that the physical properties of light and heat testify to the truth of this view, we hope, in a brief examination of a few of the facts which physiology reveals, to show how the oppositeness of the action of light and heat is turned to account in the development of living plants and animals, and in the supply of their many wants.

CHAPTER II.

FORCE.

9. THE sciences of chemistry and physics teach us, as we have already seen, that matter is not, as it sometimes appears to be, continuous throughout; but that every mass of matter, whether in the solid, liquid, or gaseous state, is an aggregation of a number of exceedingly minute bodies or separate particles of one or more of some sixty or seventy different kinds. Chemistry further shows that all particles of the same kind are of the same weight, though particles of one kind differ more or less in weight, from particles of every other kind. Thus for example a hydrogen particle is of the same weight as every other hydrogen particle wherever found; but a hydrogen differs in weight from an oxygen particle, or from a particle of any other kind. So too an iron particle is of the same weight as every other iron particle; but, at the same time, an iron particle differs in weight from a carbon particle, or from a particle of any other kind.

It is not, however, to be supposed that the actual weight of a single particle of any kind is known. Particles are far too minute objects to be distinguished by the eye, even when aided by the most powerful microscopes known to us, hence it is quite impossible to separate and weigh single particles. The proportion, however, which the weight of a particle of any kind bears to the weight of a particle of hydrogen can, as we shall see hereafter, be ascertained, and from this, the fact that all particles of the same kind have the same weight can be demonstrated.

10. Having thus learnt that matter, in all its forms, is made up of aggregations of particles, which, when of the same kind, are all of the same weight, though particles of one kind differ in weight from particles of every other kind, we have now to show that every one of the particles of which matter is composed is in the grasp, so to speak, of two forces, one of compulsion and the other of repulsion, and that by the force of compulsion the particles are drawn together into groups or masses, and held together when they are grouped or massed, and by the force of repulsion the particles are at the same time kept apart particle from particle.

11. If then we procure a number of short straight bars, square in cross section and with square ends, of one of the elementary substances, such, for

example, as iron, taking care that the metal in the bars is perfectly pure, and that the bars are all throughout uniformly of the same density, of the same length, and of the same breadth and thickness, and therefore of the same volume, and of the same weight, one as another; and, borrowing from an engineer a machine for testing the tensile and compressive strength of materials indicating exactly the amount of the load or force by which any solid body under examination is at the time strained; also instruments for measuring accurately the dimensions of solids, and for ascertaining the weight of any solid body; and from an electrician a thermo-electric pile with a galvanometer attached for the purpose of ascertaining temperature, proceed to examine the bars of iron: we shall find, if we take one of the bars and, after securing one end of it in the machine, apply a load or rending force to the other end of the bar tending to tear the bar across, that so long as the load or force is not very great the bar will successfully resist its action; but if, however, the load or force applied to the bar is continually increased the bar will be continually lengthened, and after a time will give way and be torn across.

If now we take two of the bars together, instead of a single bar, we shall find, making allowance for the roughness of all practical tests of this sort, that twice as great a load or force as will suffice to

break a single bar will be required to break two bars together. Similarly if we take three bars together, we shall find that three times as large a load or force as will suffice to break a single bar will be required to break three bars together; also four times as large a force as will suffice to break a single bar will be required to break four bars together, and so on.

Or if, on the other hand, we take one of the bars and instead of putting it under a tensile strain, put it under a compressive strain by applying, after one end of the bar has been secured, to the other end a load or compressive force tending to crush the bar; we shall find, if we note the load or force required to crush a single bar, and make allowance as before for the roughness of practical tests of this sort, on testing two bars together in the same way as the single bar was tested, that twice as large a load or compressive force as will suffice to crush the single bar will be required to crush two bars together. Similarly we shall find that three times the load or force that will suffice to crush a single bar will be required to crush three bars together; and four times the load, or force, that will suffice to crush a single bar, will be required to crush four bars together, and so on.

But since the bars are all of the same weight, and theoretically may all be assumed to be precisely of

the same weight, and since all are made of the same elementary substance, which may theoretically be assumed to be in a perfectly pure state; since also all particles of an elementary substance are of the same kind, and are therefore, as we have already seen, all of precisely the same weight: it follows that all the bars may be assumed theoretically to be made up of precisely the same number of particles one as another.

Again, since each of the bars may be assumed theoretically to be, throughout its entire length, everywhere of the same uniform density, and everywhere of the same uniform breadth and thickness, also everywhere throughout its breadth or thickness of the same uniform length; and since this perfect uniformity in the bars is clearly impossible unless the particles of which the bars are made up all have the same volume one as another, and unless in all the particles the length of the particle is the same as its breadth or thickness, also unless the particles are all symmetrically arranged: it is plain that each of the bars may be theoretically assumed to be made up of a number of rows of single particles, in which the particles are joined together end to end, thus making up a number of rows of particles of the same length as the bar arranged side by side in the bar, much in the same way as pieces of thread are arranged side by side in a hank of

thread, except that the rows of particles, instead of being as loose as the pieces of thread in a hank of thread, are cemented together side by side, thus making up a compact whole bar. For if proper appliances for dividing up a bar without either straining the metal or causing waste were available; and if, at the same time, our powers of perception and of manipulation were extended so far as to enable us to distinguish and divide between single particles, it is plain that a bar of uniform density throughout, made up of particles each having its length the same as its breadth and thickness, and all being of the same volume, and being symmetrically disposed so as to make up a bar square in cross section, with breadth and thickness perfectly uniform throughout its length, and with square ends and length perfectly uniform throughout its breadth and thickness, could be divided up longitudinally by a series of cuts parallel to one of the sides of the bar into a number of slices each of the full length and width of the bar, and each of the thickness of a single particle; and that then all of these slices would be precisely similar to each other, being of the same uniform density, length, breadth and thickness, and of the same weight, and all containing the same number of particles. And it is also clear that each of the slices could then be further divided up by a series of cuts parallel to one of the edges of the slice

into a number of rows of single particles of the full length of the bar, with the same number of particles in each row. And thus the bar would be divided up into a number of bars, each consisting of a single row of particles.

Since all the bars are uniformly throughout of the same length, breadth, and thickness, it is clear that they may all be looked upon as containing the same number of rows of particles one as another. Hence two bars will contain twice as many rows of particles as a single bar contains. Also three bars will contain three times as many rows of particles, and four bars four times as many rows of particles as a single bar contains. But we have seen that to break two bars together, whether by rending or crushing, requires twice as large a load or force as that which will suffice to break a single bar. Similarly, to break three bars together requires three times as large a load or force, and to break four bars together requires four times as large a load or force as that which will suffice to break a single bar. Hence, we may say, that if a single bar containing any number of rows of particles requires a certain load or force to break it by rending, and a certain load or force to break it by crushing, then to break twice that number of rows of particles by rending will require twice the load or force which sufficed to break by rending the smaller number of rows, or by

crushing twice the force which sufficed to break by crushing the smaller number of rows of particles. Similarly, to break three times that number of rows of particles by rending will require three times the load or force which sufficed to break by rending the original bar, or by crushing three times the load or force which sufficed to break by crushing the original bar. Also, to break four times that number of rows of particles by rending, will require four times the force which sufficed to break by rending the original bar, or by crushing four times the force which sufficed to break by crushing the original bar. Hence we may conclude that when any one of the bars is loaded or strained by a load or force tending either to tear, or to crush it, each row of particles in the bar offers an equal amount of resistance to the action of the load or force. And further, that if it were possible to obtain and test a bar made up of a single row of particles, then such a bar would be able to resist the action of a rending load or force tending to tear its particles apart half as large as the rending load, or force, which a bar made up of two similar rows of particles could resist; also a crushing load or force half as large as the crushing load or force which a bar made up of two similar rows of particles could resist. Also, that it would be able to resist the action of a rending load or force, or that of a crushing load or force, one-third of the rending load,

or force, or of the crushing load, or force, which a bar made up of three similar rows of particles could resist.

But, in order that a number of separate particles arranged in a single row may be able to hold together so far as to resist the action of a load or force tending to tear them apart, and at the same

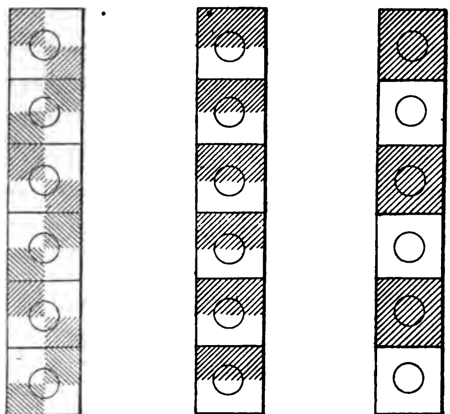

Fig. 1. *Fig. 2.* *Fig. 3.*

Showing rows of particles enormously enlarged.
Holding on particles or portions of particles are shaded.
Holding off particles or portions of particles are unshaded.

time to hold each other off so far as to be able to resist the action of a load or force tending to crush them together, it is clear that either each particle must, at the same time, hold on to and hold off the o particles on either side of it in the way shown ig. 1; or every particle must hold on to the next

particle to it on one side and hold off the next particle to it on the other side in the way shown in Fig. 2; or else the particles must be of two natures, the one nature being endued with the power of holding on to, and the other nature with the power of holding off other particles, and be arranged in pairs so that the particles endued with the power of holding on may alternate with the particles endued with the power of holding off other particles in the way shown in Fig. 3. But though something may doubtless be said in favour of each of these three views of the way in which particles in a row are enabled to resist the action both of a rending and of a crushing load or force; with neither of the last two ways is it easy to see how impulses of force can travel, as we know they can, from particle to particle. Whereas the first of the three ways not only provides a road by which impulses of force may travel from particle to particle, but also has in support of it the fact that the heavenly bodies themselves, which are, as we shall see, aggregations of different masses of matter composed entirely of particles, are plainly endued with the power of holding on to, and holding off, at the same time and on the same side, other heavenly bodies. We may therefore perhaps safely conclude that single particles possess the same powers as are possessed by particles when massed together in the heavenly bodies, and that every particle, in a row of particles,

both holds on to and holds off the particles on either side of it in the manner shown in Fig. 1.

12. If now, in place of testing bars of iron, cubes of that metal are tested, it will be found that a cube of iron is able, on all sides, to resist the action both of a rending and of a crushing load or force. And from this we may conclude that a particle of iron both holds on to and holds off the other particles of iron contiguous to it on all sides in the same mass; and indeed the accuracy of this conclusion will be confirmed if masses of other form than the cube are tested.

Similarly, if bars, cubes, and masses of other form of the other elementary or compound substances, in the solid state, are then tested, it will be found that all to a greater or less extent are able to resist the action both of rending and of crushing loads or forces.

Hence we learn that every particle of matter in the solid state is able, to a greater or less extent, to hold on to and hold off all other particles contiguous to it in the same mass of matter.

We shall see hereafter that particles of matter in the liquid and gaseous states are also able to hold on to and hold off all other liquid or gaseous particles contiguous to them in the same mass, though of course neither liquid nor gaseous particles have the same power of holding on to other liquid, or gaseous particles that solid particles have.

13. We have now to endeavour to show that the particles which, as we have thus seen, are able both to hold on to and hold off other particles contiguous to them in the same mass of matter, hold on to each other by the action of compulsive force, which binds them together, particle to particle, and hold off each other by the action of repulsive force, which tends to separate them particle from particle.

14. If then a bar of iron, similar in all respects to the bars used in the previous experiments, is strongly heated and then measured, it will be found to have expanded in every direction, though at the same time, if care was taken to keep the bar, while it was being heated, surrounded with some substance which has no chemical action upon iron, it will be found that the bar has not increased in weight. From the fact of the bar thus, under the action of heat, expanding and therefore increasing in volume, without receiving an increase of weight, or of the number of particles of which it is made up, we learn that the effect of adding heat to the bar is to drive the particles of the bar further apart one from another, or to confer upon some or all of the particles an increased power of holding off other particles.

But if while the bar is hot, its power of resisting the action of a rending load or force tending to tear it across is tested in the same way as the strength of the other bars was tested, it will be found that

the bar while hot is much softer, and less able to resist the action of a rending load or force than a cold bar is. We thus learn that the addition of heat to the bar, while it increases the power of the particles in the bar to hold each other off, diminishes the power of the particles to hold on to each other.

If the bar is further heated continuously, it will continue to expand or increase in volume, and at the same time to decrease in strength; until at length, if the heat is sufficiently great, the bar will melt, its particles having lost the greater part of the power of holding on to each other, which they before possessed. If the heat is continually increased, the molten metal will assume the gaseous form, in which the volume of the mass will have enormously increased, showing that the particles have gained in a high degree an increase in the power of holding each other off, whilst at the same time their power of holding on to each other will have been to a corresponding extent diminished.

We can actually show that compulsive force passes off from a bar when it is heated. For if the bar is made up, along with a bar of some other suitable metal, into a pair of a thermo-electric battery, and then heated at the junction of the two metals, a current, which though a very weak one, be shown to exhibit the action of attractive or

compulsive force will pass from one bar to the other. Or again, the luminous rays which the bar, in common with other solid bodies, emits when it is heated to a white heat, can, if collected by a lens and made to impinge upon a mixture of equal volumes of the gases hydrogen and chlorine, be shown, by their effect in compelling the particles of the two gases to unite together in chemical combination and form the compound substance hydrochloric acid, to exhibit the action of compulsive force.

If the bar, after being heated, is allowed to cool, it will continually give off or radiate heat, which may be collected and made to produce expansion, or an increase of volume, and at the same time a diminution of strength, or power to resist the action of a rending force in other bodies.

The bar as it cools will contract to the volume it occupied before it was heated, showing that its particles have lost the increased power of holding each other off which they gained by the process of heating. The power thus lost by the particles of the bar can be shown to have passed to the particles of the other substances, which were heated and expanded by the bar in cooling.

If now, however, we take a stout cylinder closed at one end and furnished with a tightly-fitting piston, and, after filling the cylinder with some gas such as chlorine, and placing the cylinder in a vertical posi-

tion, with the handle of the piston uppermost, apply a heavy load or weight to the handle of the piston so as to force the piston down in the cylinder, and thus compress the gas, by applying to it the force of gravity or the attractive force of the earth, we shall find that the gas as it becomes condensed becomes also heated. If we continually increase the load upon the piston, so as to compress the gas more and more, in the end the gas will become liquid; and finally if the same process is continued with the liquid, and heat is at the same time abstracted from it, the liquid will become a solid. If the solid thus obtained from the gas is examined, and the dimensions of the solid mass are measured, it will be found that the mass has gained in comparatively a high degree the power of resisting the action of a rending force, but at the same time its volume has greatly decreased, showing that though the particles have gained in a high degree the power of holding on to each other, they have lost to a corresponding extent the power of holding each other off. We can show by the expansive effect of the heat abstracted from the gas upon the substances used in cooling the gas, that the holding off power which the particles of the gas lost in assuming the solid condition, passed off to the particles of the substances used in cooling or abstracting heat from the gas.

We have thus seen that when increments of heat are communicated to a solid iron bar, the holding off power of the particles of the bar is so much increased, and the holding on power so much diminished, that the particles assume the liquid, and ultimately the gaseous condition, and disperse, being no longer able to hold together. We have also seen that, when increments of an attractive force are constantly communicated to a quantity of gas, the holding on power of the particles of the gas is so much increased, and the holding off power of the particles so much diminished, that ultimately the particles assume the liquid condition; and if the process is continued to the liquid and heat at the same time abstracted, the particles assume the solid condition, and unite into a solid mass. We have seen also that when the particles of a solid lose holding on power under the action of heat, the particles of surrounding substances gain an increase of holding on power. Also, that when particles lose holding off power under the action of attractive force, the particles of surrounding substances gain an increase of holding off power. We may take other developments of compulsive force besides that of gravity; as for example, the attractive force developed in an electro-magnet by the electric current, and by applying by a suitable arrangement the attractive force of the magnet to a quantity of gas

confined in a cylinder effect the condensation and liquefaction of the gas in the same way as with the attractive force of gravity. We may take also other developments of repulsive force besides that of heat, as for example the repulsive force developed by an electric current, and effect instantaneously the vaporization of a piece of iron wire.

Having thus shown generally that when increments of repulsive force are constantly added to a solid mass, compulsive force is dislodged from about the particles and repulsive force stored up about the particles of the mass, with the effect of gradually driving the particles further and further apart one from the other, until at length the particles assume the gaseous state and disperse, having lost the greater part of the compulsive force which was stored up about them, and being no longer able to hold together in presence of the repulsive force; and having shown also that when increments of compulsive force are constantly added to a mass of gas, in which the particles have very little power of holding together, but great power of holding each other off, the effect is to dislodge repulsive force with a perceptible development of heat, and to store up compulsive force about the particles of the gas, and to draw the particles closer and closer together, until at last the gaseous mass assumes the liquid
he solid form, we may therefore conclude with

certainty that the holding on power of particles is due to the action of an attractive or compulsive force, which binds the particles together particle to particle; and that the holding off power of particles is due to the action of an expansive or repulsive force, which separates the particles thrusting them apart one from another.

15. We further learn, from the fact that the load or weight placed upon the piston of the cylinder containing gas was able to transfer to the gas in the cylinder the force of gravity or the attractive force which tends to draw the load or weight into its proper position with reference to the other masses of matter on the earth; and from the fact that under the action of the attractive force thus transferred to the gas the whole or almost the whole of the particles of the gas were condensed and brought together into a liquid mass, that attractive or compulsive force can be transferred, or can pass both from one body to another and from one particle to another, also from particle to particle in the same body.

16. We also learn, from the fact that a heated body is able to grow cool, by giving up heat to and causing expansion in surrounding bodies; and that a heated body becomes itself more or less heated and expanded all over, and ultimately assumes throughout the liquid condition, that heat or repul-

sive force can be transferred or can pass both from one body to another and from one particle to another in the same body.

17. From the fact that on the one hand the particles of a solid expand and assume the liquid form, when heat is added to them, and compulsive force taken off; and the particles of a liquid, when continually heated, expand and assume the gaseous form, as soon as compulsive force to a sufficient extent has been displaced from them; and that on the other hand the particles of a gas, when attractive or compulsive force is added, and heat abstracted, contract and assume the liquid form; and the particles of the liquid, if compulsive force is added and heat abstracted from them, contract further and assume the solid form; we learn that the solid state differs from the liquid state, in that the particles in the solid state have a greater amount of compulsive force, about them, holding them together, and a smaller amount of heat or repulsive force, about them, holding them apart, than the particles in the liquid state have; and that the liquid state differs from the gaseous state, in that the particles, in the liquid state, have a greater amount of compulsive force about them, holding them together, and a smaller amount of heat, or repulsive force, about them, holding them apart, than the particles in the gaseous state have.

Thus the solid is the state in which the particles have a maximum of compulsive and a minimum of repulsive force about them; the gaseous is the state in which the particles have a maximum of repulsive force and a minimum of compulsive force about them; whilst the liquid is the state intermediate between the solid and the gaseous, and in it neither of the forces predominate largely. The accuracy of this deduction is shown from the fact that liquid carbonic dioxide, when it is allowed to issue from a small orifice in a closed vessel, abandons altogether the intermediate liquid state, and one part, taking an excess of compulsive, and giving up the greatest possible amount of repulsive force, assumes the solid state; whilst the other part, taking an excess of repulsive force and giving up the greatest possible amount of compulsive force, assumes the gaseous state.

18. It is important to note that, in order to reduce a gas to the liquid state it is not sufficient to add pressure alone to it; nor is it sufficient alone to abstract heat from it. For, if while heat is abstracted from the gas, the pressure is constantly reduced, the gas will not liquefy. For example, in Sir G. Nare's "Voyage to the Polar Sea," vapour is recorded, at p. 226, vol i., to have been seen ascending from cracks in the ice, when the temperature in the cracks was $-2°$ Fahr. Neither will the

gas liquefy under any pressure however great unless the gas is cooled down below a certain temperature, called by Andrews the critical point (see Roscoe's "Chemistry," vol. i. p. 79, where it is stated that carbonic dioxide, which at a temperature of 0° C. liquefies at a pressure of 38·50 atmospheres, can be subjected to a pressure of 150 atmospheres without liquefying, if the temperature of the gas exceeds 30°.92, which is its critical temperature). Thus, to reduce a gas to the liquid state pressure must ordinarily be added and heat abstracted.

19. Similarly in order to reduce a liquid to the solid state pressure must be added and heat abstracted; for it appears from Roscoe's "Chemistry," vol. i. p. 226, that water, which at the ordinary pressure of the atmosphere freezes at 0° C., can, under a diminished pressure, be cooled down to −12° C. without freezing.

20. On the other hand, in the liquefaction of a solid and in the conversion of a liquid into a gas, compulsive force must be abstracted as well as [illegible] force added. For it appears from Roscoe's [illegible]try," vol. i. p. 227, that sulphur, which [illegible] 107.0° C., at a pressure of 1 atmosphere, [illegible] under a pressure of 792 atmospheres, [illegible]ture of 140.5° C. to melt it. Again, water, [illegible] boils at a temperature of 100° C. at the ordi[illegible]pressure of the atmosphere, requires, when

under a greatly increased pressure, a much higher temperature to boil it.

21. It is necessary perhaps to notice the fact that some substances, such as water, bismuth, &c., expand in passing from the liquid to the solid state, instead of contracting, as other substances do. The expansion of these substances in solidifying, and their contraction on liquefying, may be explained by the assumption that these substances adopt, in solidifying, crystalline forms, which do not fit exactly into each other; so that a solid mass made up of crystals with intervals actually occupies a greater volume than the same mass occupies in the liquid state. Hence these substances expand on assuming the solid state; and contract by the filling up of intervals, in passing from the solid to the liquid state.

22. From the fact that particles of a gas are able, in a liquid, to collect together and form bubbles, we learn that the particles of a gas, however loose their hold on each other may, at first sight, appear to be, have not altogether lost compulsive force. We have, besides, in Professor Tait's vortex rings (see "Recent Advances in Physical Science," p. 292) a beautiful example of the way particles of air hold together. The smoky air, inside the box, with which these rings are made, is in a different condition from the air outside,

and its particles, for reasons which will afterwards be apparent, in contact with the solid particles in suspension in the smoky air, hold on to each other more firmly than air particles ordinarily do; hence when, by a smart blow delivered upon a towel or piece of cloth stretched across the box on one side, from which the woodwork has been removed, a mass of smoky air has been expelled from a round hole in the opposite side of the box, the particles in the mass of smoky air hold together after the mass has been expelled from the box; and holding together the mass takes the form of a ring; because the particles at the edge of the mass cling to the sides of the hole, and start with diminished force and velocity; whilst those in the middle being comparatively unimpeded, start under the full force of the blow, and open out, rotating easily the more slowly moving particles at the outer edge; thus forming a hole through the middle of the mass, for precisely the same reason that the particles in the middle of a disc of any soft substance open out, when a blow is struck on the middle of the disc, and form a hole in the middle of the disc. The after movements of these rings of smoky air as they pursue or impinge against each other present some peculiarities which will be appreciated when we consider the subject of motion.

23. From the fact that particles of a liquid draw

together and form drops, or move in streams, we learn that the particles of a liquid have a considerable amount of compulsive force about them.

24. From the fact that a film of air is often seen to be attached to the surface of a solid, when the solid is plunged into a liquid; and from the fact known to chemistry that some solids, when in a porous condition, such as spongy platinum or carbon, are able in a very marked way to condense gases in their pores, we learn that the surface particles of a solid hold on to, or are connected with the particles of gasses contiguous to them.

25. From the fact that films or drops of liquids are often seen attached to solids; also from the fact that minute tubes formed in solids are able to draw liquids into them by the process of what is called capillary attraction; and from the fact that liquids are able, in many cases, to dissolve solid masses, pulling them, as it were, to pieces, we learn that the surface particles of a solid hold on to, or are connected to, the particles of a liquid contiguous to them.

26. From the fact that a stream of a liquid carries down with it bubbles of a gas through which it passes: also from the fact that, when liquids and gases are in contact, portions of the gases are generally dissolved in the liquids, we learn that liquid particles hold on to, or are connected to, the particles of any gas contiguous to them.

27. We thus learn also that masses of any solids, when placed in a mass of liquid, or of a gas, are directly connected together by the particles of the gas, or of the liquid in which the solid masses are placed.

28. But though the surface particles of a solid can thus be shown to hold on to the particles of a gas, or of a liquid contiguous to them, and the particles of the gas, or liquid thus connected to the particles of the solid in their turn hold on to the other particles of the liquid, or gas contiguous to them more firmly than the particles of the gas or of the liquid generally hold on to each other, so that a film of the gas or of the liquid is formed about the surface of the solid; or when the solid is finely divided up and distributed, as silt in a river, or as smoke in the air, a mass of muddy water is formed, having more coherence than clear water, as is sometimes well seen at the junction of two rivers, a clear and a muddy one, when the water of the muddy river for a long distance keeps apart from the clear water, or a mass of smoky air is formed, having more coherence than a similar mass of pure air, as is well seen in the case of Professor Tait's vortex rings, referred to in paragraph 22: it is clear that the particles of the solid do not hold on to the particles of the gas, or of the liquid as strongly as they hold on to other solid particles. For if two solid masses

of the same substance are brought together in a gas, or in a liquid, the two masses will not generally unite to form a single mass even though the surfaces are accurately fitted together, and if a portion is detached forcibly from any solid mass, the broken surfaces will not generally unite, even when they are brought immediately together: though there are exceptions to this; for it is found that two pieces of freshly cut lead with smooth surfaces, or two perfectly polished plates of glass, or two pieces of cast iron with true surfaces, as in Whitworth's planes, will cohere (Miller's "Chemistry," vol. i., p. 70). We thus learn that the exposed sides of the surface particles of a solid lose holding on power both in a liquid and in a gas. At the same time, since liquid particles have about them a greater amount of compulsive force than the particles of a gas have, it is clear that the exposed sides of the surface particles of a solid will lose less holding on power when the solid is immersed in a liquid than when it is immersed in a gas. Accordingly we find that grains of dust and sand, and many other substances which when dry do not hold together, when wetted cling together and manifest a considerable amount of holding on power.

29. The particles in a liquid are free to turn, and are easily displaced at any time; consequently the particles at the surface of a liquid are constantly

presenting fresh faces to the outside: hence two masses of the same liquid unite easily, when they are brought in contact, provided that the temperature of both of the masses is the same. Hence also, if the surfaces of two solid masses of the same substance are heated, until the particles at the two surfaces become mobile and free to turn, the masses will unite, if the surfaces are then forcibly brought together; thus masses of iron are joined together by welding.

30. We have thus seen that particles, whether in the solid, liquid, or gaseous state, hold on, in a greater or less degree, to all other particles, whether in the solid, liquid, or gaseous state, contiguous to them, by means of compulsive force about them, drawing particle to particle. We have also seen that in any mass of matter, whether in the solid, liquid, or gaseous state, the particles, of which the mass is made up, are kept apart by repulsive force acting about the particles and separating, or keeping off particle from particle. But though particles are thus held together and kept apart by the forces of compulsion and repulsion about them, it is plain that particles do not consist solely of force. For in chemistry, as already stated, some sixty or seventy different kinds of particles are recognized; and each of these sixty or seventy different kinds of particles has a constant form of its own, in which a different

disposition of the forces of compulsion and repulsion and a different capacity for retaining these forces prevail, from those found with the other kinds of particles. This constant form, and the peculiarities which distinguish it, are retained by each kind through all the changes, which, being due, as we have seen in paragraph 17, to variations in the relative proportion in which the two forces of compulsion and repulsion are present about the particles, occur when particles change from the solid to the liquid, or from the liquid to the gaseous state, or *vice versâ*; so that a particle of any kind at once returns to the normal state of particles of its kind as soon as it is freed from the influences by which the transformation to another state was effected: also this constant form is retained, through all the changes, often of a most complicated character, which particles undergo when they enter into chemical combination with particles of other kinds, whereby, as we shall afterwards see, by the addition, or abstraction of force, groups of particles are formed, which, when collected into masses, make up masses often differing in all respects from any of the elementary substances made up of aggregations of any of the particles in the groups taken singly; so that the particles return at once to the normal condition of particles of their kind, as soon as they are dissociated from these groups and freed from the

influence of the other particles composing those groups. And it is manifest that particles, which thus retain constant forms and constant differences throughout a great variety of changes, all involving alterations in the amount and distribution of the two forces of compulsion and repulsion present about the particles, cannot be made up alone of two variables, such as are these two forces of compulsion and repulsion; but must include also in their composition a constant element. Otherwise, in some of the many changes which particles undergo, all involving variations in the relative proportions, as well as in the quantities in which the forces are present about the particles, it would necessarily happen that particles of the several kinds, instead of constantly retaining each a constant form peculiar to itself, would be from time to time transformed into particles of other kinds, now of one sort and now of another. We thus conclude that each particle consists of a central atom of constant form in the grasp of the two forces of compulsion and repulsion, which form a kind of sheath, or envelope about the central atom, on the one hand connecting it with, and on the other hand separating it from all particles, of whatever kind, or in whatever state, immediately contiguous to it.

31. The idea of the two forces thus forming a sheath or envelope about a particle must not be too far

strained, since there is no actual partition or demarcating surface between the portion of force acting upon any particle, and that acting upon the opposite side of any other particle contiguous to that particle on that side; and the nature of the connexion between any two contiguous particles, probably more nearly resembles that of two bodies held together by an elastic tie in the case of compulsive force and that of two bodies kept apart by an elastic strut in the case of the force of repulsion, than anything else. Nevertheless, since, even when a particle separates from a liquid, or solid mass, and moves off in the gaseous form, the forces still retain their hold of the particle, this idea of a force sheath or envelope about a particle, is a convenient one for expressing the way in which the forces range themselves about the central atoms: and we may perhaps not incorrectly look upon the sheath or envelope of any particle as extending, on any side, half-way between the central atom of the particle and the central atom of the next particle contiguous to it, on that side.

32. Since compulsive force tends to draw the central atoms of contiguous particles together, and thus contract the force sheath, or envelope of the contiguous particles on the sides on which it acts; and since repulsive force tends to drive contiguous particles apart, and thus expand the force sheaths

or envelopes of the contiguous particles on the sides on which it acts; since also the two forces of compulsion and repulsion acting side by side at once connect all particles together and keep all particles apart, and thus fill all space in such a way that on the one hand no two particles can be drawn closer together on one side by an increment of compulsive force, without a corresponding displacement of repulsive force, involving the separation to a similar extent of two particles, or a similar extent of separation spread over more than two particles, on some other side; and on the other hand, no two particles can be driven further apart on any other side by an increment of repulsive force without a corresponding displacement of compulsive force, involving the drawing together to a similar extent of two particles, or a similar extent of contraction spread over more than two particles, on some other side; it follows that the relative proportion in which the two forces of compulsion and repulsion are present about any two contiguous particles on any side determines the distance which separates the two contiguous particles on that side and the extent on that side of their respective force sheaths.

33. It follows also that there must be two ways in which two contiguous particles can be drawn closer together, viz. either by transferring compulsive force from particles on some other side to the two parti-

cles, and thus displacing from the two particles repulsive force, which will produce expansion between the particles on the other side from which compulsive force was transferred; or by transferring repulsive force from the two particles to other particles on some other side, and thus displacing from the particles on the other side compulsive force, which passing to the two particles will draw them closer together.

Similarly there must be two ways of driving two contiguous particles further apart, viz. either by transferring repulsive force from the particles on some other side to the two particles, and thus displacing from the two particles compulsive force, which will draw together the particles on the other side from which the repulsive force was transferred; or by transferring from the two particles to other particles on some other side compulsive force, and thus displacing from those other particles repulsive force, which passing to the two particles will drive them apart, taking the place of the transferred compulsive force. Accordingly we find this in practice to be the case. For if we perform an experiment suggested in Miller's "Chemistry," vol. i., p. 51, with which a glass cylinder closed at one end is furnished with a tightly-fitting piston and then half filled with some coloured gas such as chlorine, we shall find that the chlorine gas will

be visibly condensed, showing that the particles of the gas are drawn closer together, if either, after placing the cylinder in a vertical position with the handle of the piston uppermost, we weight the piston, and so transfer to the particles of the gas the attractive or compulsive force of gravity, which acts directly upon the particles of the weight in the piston; or if we transfer heat or repulsive force from its particles to the particles of some freezing mixture with which the cylinder is surrounded, so that particles of the freezing mixture receive heat and expand or are driven apart, while the particles of the gas receive compulsive force. Again we shall see that the gas will visibly expand, showing that its particles have been driven further apart one from another, if either we transfer from some heated body heat or repulsive force to the gas, allowing at the same time the piston to rise in the cylinder; or if we transfer compulsive force from the gas to the particles of the air outside by forcibly drawing up the piston. We note with reference to this experiment that, when the piston is forcibly driven down, the gas, as we have already seen, being condensed in the cylinder, is also heated, showing that heat or repulsive force has been displaced, and is passing off to surrounding objects; also that, when the piston is forcibly drawn up in the cylinder, the expanded gas is cooled, showing that the particles

of gas are taking heat or repulsive force from the particles of air surrounding the cylinder, to fill up the place so to speak of the compulsive force transferred.

Hence we learn that there are two ways of producing contraction, namely, first by the direct action of compulsive force on the side on which the contraction takes place; and second, by the action of compulsive force displaced from some other side by the direct action, on that side, of repulsive force. So also there are two ways of producing expansion, viz. first, by the direct action of repulsive force on the side on which the expansion takes place; and second, by the action of repulsive force displaced from some other side by the direct action of repulsive force on that side.

33. When therefore we have evidence of the presence and action of compulsive force, and notice that in connexion with the action of that compulsive force an expansion of the volume of any mass of matter takes place, we may consider that the expansion is due to the action, upon the particles of the expanded mass, of repulsive force displaced from the particles of some other mass upon which the compulsive force is acting directly.

Similarly when we find in connexion with the action of repulsive force a contraction in the volume of any mass takes place, we may consider that the

contraction is due to the action of compulsive force displaced by the repulsive force from the particles of some other mass on which it acts directly.

34. Having thus seen that particles consist each of a central atom in the grasp of the two forces of compulsion and repulsion, which form a sort of sheath or envelope round the central atom, connecting it with, and separating it from the central atoms of all particles of every kind contiguous to it; also that the two forces of compulsion and repulsion, thus connecting particle with particle and separating particle from particle, fill up together all the intervals in space between the central atoms of particles, whether these particles are drawn close together in solid or liquid masses, or dispersed in gaseous masses; so that although no increment of either of the forces can attach itself to any particle, mass, or body without displacing, from that particle, mass, or body, a corresponding amount of the opposite force; yet through roads of communication, for both the forces, are open on every side, so that increments, or decrements of either of the two forces, whenever they can force their way, can at any time travel from particle to particle from mass to mass and from body to body from the one side of the universe to the other; we may now go on to consider the way in which the two forces of com-

pulsion and repulsion are disposed or distributed about the central atoms.

35. Now single particles, as we have seen, are bodies so exceedingly minute that it is quite impossible for the eye, even with the help of our best microscopes, to distinguish them; and therefore it is useless for us to hope to discern with the natural eye the way in which the forces of compulsion and repulsion are disposed alongside of each other about the central atom of a particle. Nevertheless the natural eye, by detecting the peculiarities of form and structure, which different masses of matter under similar circumstances, or similar masses of matter, under different circumstances, adopt, may enable the imagination to institute comparisons and in this way bit by bit to make a more or less complete picture of the particle; so that although we cannot view a single particle with the natural eye, we may be able to view one with the eye of the imagination.

36. We may notice then that solids usually occur in masses bounded by plane faces, though each face is often broken up into an enormous number of planes. We have in the beautifully regular crystalline forms, which many substances adopt in solidifying, striking examples of masses bounded with plane faces. We have other examples in the perpendicular faces of cliffs and in the surfaces of broken masses of rock

generally. It is, when solid masses are exposed to the action of running water, or to that of other liquids, or of gases; as when hill sides are exposed to the action of rain, and to that of the torrents which rain pours down them; or when masses, such as those in the various animal and vegetable forms, are built up, and intersected by streams of blood or of sap, then that the surfaces of solid masses become rounded.

In masses of liquid, as we may see in a drop or in a stream of water, or by watching a ship at sea as it sails away from us and disappears bit by bit—first the hull, then the sails, and lastly the tops of the masts vanishing from our sight—or in the waves, the exposed surfaces are always rounded, though sometimes the amount of curvature is almost inappreciable; at the same time the surfaces in liquid masses are regular.

In masses of gas, as we may see, in the clouds, or in the smoke, in which the form of the gaseous masses is indicated by the liquid, or solid particles in suspension in the mass, the surfaces are rounded and at the same time exceedingly irregular and constantly shifting.

From appearances such as these, we conclude that the particles, of which the shifting irregular rounded gaseous masses are made up, must necessarily be extremely mobile, able to transmit force in every

direction, and constantly in motion, being driven apart, or drawn together by every variation of temperature, or pressure, and ready to move at once should any impulse of force reach them.

In regard to the particles of which liquid masses are made up, we conclude from the regular rounded forms which liquid masses adopt, and from the readiness with which these masses yield to the action of impulses of force, that the particles of which a liquid mass is made up are able to transmit force in every direction, and are also mobile, though they have far less mobility than particles in the gaseous state have.

From the evenness, stiffness, immobility, and regularity of solid masses, we conclude that solid particles are constant and regular in form, transmitting force impulses onward in the same direction as that from which they arrive, and very feebly in any other direction, but themselves yielding very slowly to the action of force.

37. From the fact that the two sides of crystals, and of animal and vegetable forms generally are symmetrical, we conclude that the opposite sides of solid particles are generally similar. From the fact that many substances in nature, when in the solid state, besides having in common with all other substances each, when they are elementary substances, its own peculiar form of particle, or, when they are com-

pound substances, each its own peculiar method of arranging the particles in the groups of particles of which it is made up, also have each its own peculiar crystalline forms to which it steadfastly adheres; so that each of these substances has, in the crystalline forms which it adopts, to quote from Dana's "Mineralogy," "some peculiarity, some difference of angle, or some difference of cleavage structure, which distinguishes it from every other mineral:" also from the fact that many of these crystalline forms have highly polished faces moulded with an accuracy which cannot be surpassed; and in addition have, many of them, the property of cleavage, or of splitting readily into layers in certain directions; we may infer that in these substances the particles are of uniform size and regular form; just as certainly as an engineer, looking at a well-built brick wall, is able to infer, when he sees regular courses, fine joints, and vertical plane faces, that the wall has been built with well-shaped bricks of uniform size. We know that though very neat and regular piles can be built with round shot of uniform size, and indeed such piles may be, or might have been in the days of smooth-bore ordnance, seen any day at any arsenal; yet that walls with vertical faces cannot be built with round shot. To build a wall with vertical faces, and regular joints and courses, bricks or stone of suitable shape are necessary. So also when

crystals of regular form, having like the brick wall regular courses or cleavage planes, are built up, we may be sure that material in the form of particles of uniform size and regular shape has to be provided.

38. But we can go a step further, and from the crystalline forms adopted by some substances in solidifying, we can deduce the actual form adopted by the sheaths, or force envelopes, as defined in paragraph 31, of the particles. For we find that many substances, such as rock salt, galena (lead sulphide), &c., crystallize in the form of the cube; and, with some of these substances, we may obtain cubic crystals by slowly evaporating solutions of the substances, and then, taking one of the cubic crystals, we may, by proper manipulation, feed the crystal with a solution of the same kind as that by which the crystal was originally deposited, in such a way that the crystal while continuing to increase in size shall constantly maintain the cubic form.

Again, if we take a cubic crystal of some substance, such as galena, which has cleavage planes parallel to the faces of the cube (Dana's "Mineralogy"), we can reduce such a crystal in size to any extent, while still keeping it in the cubic form, by taking off a layer of the same thickness from each of the faces of the cube in succession. We may thus, as it were, take the crystal to pieces layer by layer, still keeping it in the form of a cube,

by stripping off from the crystal each time a complete cubic shell.

But now, if we think over these facts in connexion with the way a brick or stone wall is built up, we shall see that crystals, which are thus built up of small particles layer by layer, and yet constantly retain the cubic form; and crystals, which can thus be taken to pieces layer by layer, and yet constantly retain the cubic form, must, almost of necessity, be built up of particles, which are themselves cubes of uniform size; as otherwise the particles could not at once drop into their places so as to complete the several layers or shells with perfect regularity.

39. We learn from chemistry that rock salt and galena, as well as other substances, such as fluor spar and silver chloride, which crystallize in the form of the cube, are compound substances generally containing two particles in each of the groups of particles of which they are made up. In the case of rock salt, each of the groups of particles in it consists of a particle of the elementary metal sodium united to a particle of the elementary gas chlorine. In the case of galena, each of the groups of particles in it consists of a particle of the elementary metal lead united to a particle of the elementary substance sulphur. Assuming then that each of the groups of particles of which rock salt and galena are respec-

tively made up is in the form of a cube, we may, remembering that both compulsive and repulsive force are distributed over every side of a particle, as was seen at paragraph 12, conceive that, in the case of the rock salt groups, a particle of sodium and a particle of chlorine, and, in the case of the galena groups, a particle of lead and a particle of sulphur, are arranged side by side in the way shown in

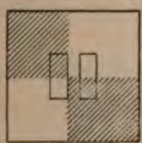

Fig. 4.

Section showing on an enormously enlarged scale the assumed arrangement of the sodium and chlorine particles in one of the groups of particles of which rock salt is made up. The shaded portions indicate the portions of the force sheath or envelope about the central atoms occupied by compulsive force. The unshaded portions of the force sheath or envelope indicate the portions occupied by repulsive force.

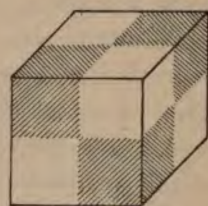

Fig. 5.

Elevation showing the assumed distribution of the forces of compulsion and repulsion in a cubic form, in the force sheath or envelope of one of the groups of particles, consisting of a sodium united to a chlorine particle of which rock salt is made up. The shaded portions indicate compulsive, the unshaded portions repulsive force.

section, in Fig. 4, and, in elevation, in Fig. 5, in which the force sheath or envelope, defined as in paragraph 31, of each group, is shown in the form of a cube divided up into eight small cubes, four of attractive and four of repulsive force, arranged two and two about each of the two central atoms making up the group; so that there are two small cubes of com-

pulsive alternating with two small cubes of repulsive force about the sodium particle, and two small cubes of compulsive alternating with two small cubes of repulsive force about the chlorine particle, of each group; and the eight small cubes together make up one large cube of the form shown in Fig. 5, having its six faces similar one to the other, each face being divided up into four squares, two of compulsive and two of repulsive force, representing the force bonds by which the group is connected with the group next it on each side.

Now since all the faces of the cube shown in Fig. 5 are similar one to the other, and the cube is perfectly symmetrical throughout, it is clear that if, for any reason, a number of precisely similar cubes were to be brought within the influence of such a cube in a central position, so as to be attracted the cube, then each of the six faces of the cube ould attach to itself another cube; and there l then be six outer cubes grouped symmetri- about the six faces of the central cube.

pposing now that the four side-faces of the six cubes, thus arrranged about the central cube, to take to themselves additional cubes, in such way that one additional cube should be taken tween each pair of side faces opposite to each ther: there would then be eighteen outer cubes, nged symmetrically round the one central cube in

such a way as to form three belts intersecting each other about the one central cube, and to make up a figure wanting but one additional cube at each of

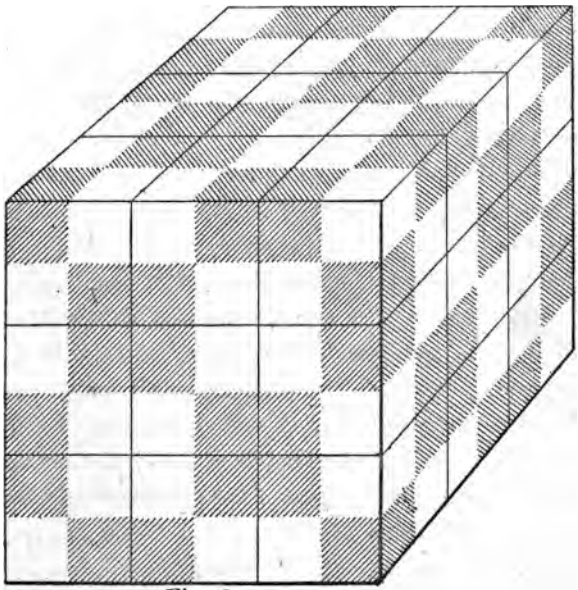

Fig. 6.

Cubic crystal built up of twenty-seven small cubes of the form shown in Fig. 5, arranged with one cube in the centre, and the remaining twenty-six cubes grouped, so as to form a complete cubic shell, about the central cube, and showing nine cubes in each face. The shaded spaces indicate compulsive force: the unshaded spaces indicate repulsive force.

its eight angles, to make up a complete cubical crystal containing twenty-seven cubes. If we suppose the eight additional cubes required at the angles to complete the figure to be taken, there

will then be twenty-six outer cubes, forming a complete cubic shell about the one central cube. The whole forming together a cubic crystal, of the form shown in elevation in Fig. 6, built up of twenty-seven cubes, arranged symmetrically so as to show nine cubes in each face of the crystal and so that the six faces of the crystal are precisely similar the one to the other.

Supposing that when the first cubic shell has thus been completed about the single central cube, the nine exposed faces of the cubes on each of the six sides of the crystal, shown in Fig. 6, each and all take to themselves an additional cube, so that there will be nine additional cubes added to each face of the crystal, making a complete layer, one cube deep, over each face; and that then a single row of cubes is added to each of the twelve edges of the crystal, so as to connect the edges of the six layers of cubes upon the six faces of the crystal together, it is clear that a second complete cubic shell will be added to the crystal outside the first cubic shell; and that the crystal will then be in the form of a cube, made up of 125 small cubes arranged symmetrically, in such a way that each of the six faces of the crystal will be precisely similar one to another.

A third cubic shell can then be added in the same way as the second cubic shell was formed, and so on.

It will be noticed that the first cubic shell is completed in three stages, and that the second and subsequent cubic shells are completed in two stages.

But now suppose that, during the progress of the second stage in the formation of the first cubic shell, while an additional cube is being taken up between each pair of side faces of the six outer cubes ranged about the single central cube, an additional cube is also taken by the outer face of each of these six outer cubes; and that these six additional cubes, thus attached to the outer faces of the six cubes ranged about the single central cube in the second stage of the first cubic shell, shall, during the progress of the third or last stage in the formation of the first cubic shell, take to themselves an additional cube to each of their four side faces and to their outer face: then, when the first cubic shell is completed, there will be a pile with a base of five cubes and a height of two cubes projecting from either extremity of each of the three axes of the cubic crystal. Suppose then that, during the progress of the first stage in the formation of the second cubic shell, each of the exposed faces both at the top and at the sides of each of the piles thus formed at each extremity of the three axes of the cube, takes to itself an additional cube, and that the exposed faces of these additional cubes in their turn

take, during the progress of the second, or last stage in the formation of the second cubic shell, each to itself, an additional cube, so that during the formation of the second cubic shell, two cubes are added to the height of each pile of cubes thus raised about either extremity of each of the three axes of the cube,—then it is plain that if the same rate of progress is continued during the formation of other cubic shells, these piles of cubes about either extremity of each of the three axes of the cube will increase in height so fast, and spread out so rapidly at the base, that by the time the third cubic shell is completed, the bases of the piles will have spread over and obliterated all the six cubic faces of the crystal, and the crystal will have been transformed from a cube into an octohedron, in which form it will subsequently remain, and continue to grow.

But let us now, on the other hand, suppose that the construction of the cubic crystal proceeded uniformly, without the formation of any excrescence at the extremities of the axes, until the first cubic shell had been completed; and that then during the progress of the second stage in the formation of the second cubic shell the exposed faces of the cubes located in the formation of the first stage of the second cubic shell should, while the rows of cubes were being adjusted along the edges of the crystal to

complete the second cubic shell, each take to itself an additional cube: then, if subsequently the same accelerated rate of progress in the outer faces were continued during the formation of other cubic shells, it is plain that the additions to the faces would proceed so fast, and the construction of the edges of the crystal would be so much retarded, that the crystal would be converted from a perfect cube into a cube with truncated edges, and ultimately into a rhombic dodecahedron.

Now the cube, the regular octohedron, and the rhombic dodecahedron are the three forms belonging to what is called the first system of crystallography (Dana's "Mineralogy"); but we have seen that all these forms can be built up naturally with particles in the form of the cube. We can understand that if the supply of particles available for the formation of the crystals is very large, the three stages in the construction of the first cubic shell, and the two stages in the construction of the second and subsequent cubic shells, will, practically, run into one another, and that then the crystal will take the form of a perfect cube; but that if the supply of particles is scanty, the several stages in the construction of each shell will be more clearly defined, and also the exposed faces of the crystal will be in a better position to obtain a supply of particles than the edges are; and thus that the

nature of the supply of particles for the formation of crystals may to a considerable extent determine whether the crystal shall take the form of a cube, or that of an octohedron, or that of a rhombic dodecahedron, either in a perfect, or in a modified form.

40. We may assume that, in the formation of a crystal in a liquid, the particles arrange themselves in the order adopted in the crystal, before the transition from the liquid to the solid state actually takes place: for we find for example from the fact, that water, which expands on solidifying, commences to expand directly its temperature falls below 4° C., though it does not actually become solid until it is cooled down to a temperature of 0° C., plain indications that the particles arrange themselves in crystalline order, with the same intervals between the different groups as are found between the crystals in the solid state long before the transition from liquid to solid actually occurs; since as we have already seen, it is to the intervals which occur between the crystals that the expansion of ice is due.

41. But though, in rock salt and galena, and other substances crystallizing in the form of the cube, regular octohedron, or rhombic dodecahedron, the envelopes of the particles may thus almost with certainty be shown to take the form of the cube, it

by no means follows that all particles take that form in their envelopes. Indeed, from the fact that many substances in the solid state are much stronger in one direction than in another, we may infer with certainty that the central atoms in such substances are closer together in one direction than in another, and therefore that the particles of such substances have envelopes of a prismatic, or other elongated form.

The envelopes of particles of a solid mass which is extended or compressed under any load, are drawn out or compressed, and in this way the change of form which the mass exhibits, is brought about.

The envelopes of particles of a liquid, or of a gas, when in motion, are constantly being extended, or compressed, as may be seen from the curls and eddies which liquid and gaseous masses in motion often exhibit. In a state of relative rest, however, we may assume that both liquid and gaseous masses adopt regular forms, and, since they both transfer force equally in all directions, we may assume that they, like some solids, adopt the cubic form for the envelopes of their particles.

42. Having thus generally glanced at the way in which the two forces of compulsion and repulsion are distributed in the envelopes of particles, we may now proceed to consider the general question of the

transference of force, which, as we have already seen in paragraphs 15 and 16, takes place between particle and particle in a mass, or between mass and mass.

Now if we test any bar by a load, or force applied gradually, and then test it by a load, or force applied suddenly, or, in other words, by a jerk or blow, in place of a steady pull or pressure; we shall find that a load or force, which if applied as a steady pull or pressure, will be successfully resisted by the bar, will break the bar immediately if it is applied by a jerk or blow. This plainly shows that the particles of a bar are only able to transfer a definite amount of force in a given time, and that if a greater amount of force reach the particles of a bar in the given time than the amount they are able to transfer, the particles yield to the force.

If again, we take an elastic rod, such, for example, as a bar of steel, or better still, a rod of India-rubber, and test it by a load or force tending to rend it, but take care that the load or force is one which the rod is well able to bear, we shall find, as has been already noticed, that the rod will first become lengthened, and at the same time contracted in diameter, and then when it is thus lengthened and contracted in diameter it will resist the force by transferring it from the end at which it is applied to the attachment at the other end. If we increase

the load, taking care that the increased load is still well within the load the bar is able to bear, we shall find that a further increase in length and a reduction in diameter occurs; and so for every other increment of force a corresponding increase in length and reduction in diameter will take place. As soon, however, as the load or force is taken off, the rod at once returns to its normal shape, decreasing in length and increasing in diameter. Here the behaviour of the rod clearly indicates that the load or force has produced compression outside of the rod, and in the direction of the source or centre about which the force is acting, and has thus, in the manner indicated in paragraph 33, displaced repulsive force, which, in its turn, has produced extension in the particles of the bar and a displacement of compulsive force away from the ends and towards the sides of the particles; and that the displaced compulsive force in its turn has drawn the particles of the bar closer together at the side, producing contraction in the diameter of the rod; also that the particles of the bar, when thus contracted, laterally are able to transfer the force communicated to them by the load at one end to the attachment at the other end in a way they could not do before they were thus contracted laterally. As soon as the load or force is taken off the rod the displaced compulsive force recovers its normal position about the particles.

If, on the other hand, a load or force tending to crush the bar is applied to the bar, a contraction in the length, with an increase of diameter, is produced, and then the further action of the load or force, if it is one which the bar can bear easily, is resisted or transferred by the particles of the bar from the end at which it is applied, to the attachment at the other end. This shows that the load or force has produced expansion outside the bar about the source or centre from which it acts, and has thus displaced from outside the bar compulsive force, which inside the bar produces contraction in the length of the bar, accompanied by a displacement of repulsive force from the ends towards the sides of the particles in the bar, where the action of the displaced repulsive force produces expansion; also, that the particles of the bar, when thus expanded laterally, are able to transfer the force communicated to them by the load at one end to the attachment at the other end, in a way they could not do until they were thus expanded laterally. When the load or force is taken off, the displaced repulsive force recovers its normal position about the particles of the bar.

We may here notice that both compulsive and repulsive force are competent to produce, when they are applied to a bar of which the end opposite to that at which the force is applied is secured to some mass of matter able to receive force from the

bar, contraction in length coupled with lateral expansion, or elongation coupled with lateral contraction, or in other words to act either as a rending or as a crushing force according as the end where the force is applied is nearer to or more distant than the other end from the centre about which the force acts. Compulsive force, on the one hand, produces elongation coupled with lateral contraction in the way already explained, when the end of the bar at which it is applied is nearer to the centre about which the force acts than the other end is, and under the same circumstances repulsive force produces contraction in length coupled with lateral expansion. Again, compulsive force, on the other hand, produces contraction in length from the direct action of compulsive force, and lateral expansion from the action of displaced repulsive force, when the end of the bar at which it is applied is more distant than the other end from the centre about which the force acts; whilst under the same circumstances repulsive force produces elongation from the direct action of repulsive force coupled with lateral contraction from the action of displaced repulsive force in the way already explained.

If a rending load or force greater than the bar is able to bear is applied to the bar, the bar will yield to the force or load, and be torn in two, its particles being unable to transfer the whole of the

force the bar receives, owing to the large amount of compulsive force displaced, from the ends of its particles. The detached portion of the bar moves to or from the centre or source about which the rending force acts, until it reaches some position where it is able to transfer to the particles of some other mass the force it receives, or the excess of force it has received; or until it reaches some place where the load or force ceases to act on it.

If, on the other hand, a crushing load or force greater than the bar is able to bear is applied to the bar, the particles of the bar being unable to transfer, in their then position, the whole of the force they receive, owing to the large amount of repulsive force displaced from the ends of the particles, will yield to the action of the load or force, and the bar will be crushed, the broken parts moving to some fresh position either towards or away from the centre or source about which the force acts; where either they will be able to transfer the whole of the force they receive, or where the load or force will cease to act upon them.

43. If, now, we attach, to the end of a steel or other bar, a small block of wood, and then, placing the block with the bar attached to it so that the block and bar may rest on the ground, apply force to the bar in the direction of its length, we shall find that, the block being small, the block and the

bar with it can be moved easily either towards or away from the source or centre about which the force acts, according as the force is one of compulsion or one of repulsion.

If the size of the block of wood is largely increased, the description and density of the wood being unaltered, we shall find that, under the same force applied in the same way as before, the block and bar will move much more slowly and to a shorter distance if the force consists of a single impulse, than before.

If the size of the block of wood is continually increased, it will be found, in the end, that the same force, which moved the small block easily, will fail altogether to move the block when it is made very large. From what we have already learnt in regard to the transfer of force, it is clear that the very large block, containing, as it does, a very large number of particles, and having a large surface and therefore a large number of particles in contact with the ground and with the particles of the air, is able to transfer to the ground and to the air all the force which it receives. On the other hand, the small block containing but a small number of particles, and being therefore in contact with only a comparatively small number of particles of the ground and of the air, is unable to transfer by that small number of particles the whole of the

force it receives; hence it moves under the force until the whole of the impulse of force has been expended, or until some position is reached where the block is able to transfer the whole of the force it receives, either because the position is a favourable one for transferring force, or because in it a diminished quantity of force reaches the block.

When heat is applied to a body, we find, if the body is what is called a good conductor of heat, and has a large extent of its surface exposed to the air, or in connexion with some other substance also a good conductor of heat, that sometimes the same amount of heat, which melts the body easily when it is enclosed by some substance which is a bad conductor of heat, and when the air is at the same time excluded, will altogether fail to melt the body when it is thus exposed to the air, or in contact with a substance which is a good conductor of heat. From this it is plain that the body melts when it does melt because its particles are unable to transfer heat to the particles of the air, or of the sides of the vessel in which it is heated, as rapidly as it receives heat. If the body, after it is melted, is confined by the sides of the vessel, or in some other way so as to be unable to move away, it will, if the heat is sufficiently great, assume the gaseous form and then escape in the form of a gas, being unable in any other way to transfer the heat it

receives. We have seen already that when a quantity of gas, in a stout cylinder closed at one end and furnished with a piston, is compressed by the application of force to the piston tending to drive it down the cylinder, the gas will, if it is unable to transfer the compulsive force thus communicated to it as fast as it receives it, and if at the same time the gas is deprived of a sufficient quantity of heat, be condensed into the liquid and ultimately into the solid state, in which the maximum amount of condensation will have been attained.

From all these experiments, beginning with that with the bar, which resisted the action of a force applied gradually, but broke under the same force applied suddenly, we learn that particles in a mass of matter, not only hold together as we have before seen by the action of compulsive force, permanently or in a measure permanently impressed upon the central atoms of all, and acting between the central atoms of contiguous particles, so as to draw them together particle to particle; and keep apart by the action of repulsive force, permanently or in a measure permanently impressed upon the central atoms of all particles, and acting by thrusting apart the central atoms of contiguous particles one from the other; but also that particles in a mass of matter hold together by transferring to the particles contiguous to them what we may call the temporarily

impressed impulses or efforts of directional compulsive force, which tend to draw the mass, as a whole, or in part, in the direction of the centre or source about which the force acts; and of directional repulsive force which tend to drive the mass, in part, or as a whole, in a direction away from the centre or source about which the force acts.

So long as the particles of a mass are able to transfer, to one another through the mass, and to particles of other substances outside the mass, the whole of the force in these temporarily impressed impulses, or efforts of directional force, which are communicated to them, there will be no motion of the mass as a whole, or a disintegration of it in part. But if the particles of the mass fail to transfer, or to pass on from one to the other the whole of these efforts or impulses of force, then a disintegration to a greater or less extent of the mass will ensue; or if the surface particles of the mass fail to transfer the whole of these efforts or impulses of force to the particles of surrounding masses of matter, then the mass as a whole will move under the force. When the mass is disintegrated, the portions separated from it move, or when motion of the whole mass takes place, the mass as a whole moves, either towards or away from the source or centre about which the force causing the motion acts, according as the force is one of compulsion, or of repulsion.

44. We thus learn that there are two kinds of Motion corresponding to the two kinds of force which we have seen to be acting. These two kinds of Motion are, motion towards a centre or source of force due to the action of compulsive force; and motion away from a centre or source of force due to the action of repulsive force.

45. If no change of position of the mass, whether as a whole or in part, takes place under the action of an impulse of force, we can understand, if we turn to Fig. 6, and taking any row of cubes in that figure consider the row of cubes to represent, on an enormously enlarged scale, a bar made up of a single row of particles, how the impulse of force is transferred from one side to another of the mass. For if the top particle of the row selected receives an impulse of compulsive force, it is clear that the first effect of the impulse of compulsive force will be to draw towards the top or first particle the one next below, or the second particle, thus displacing repulsive force, which drives the second and third particles further apart. The impulse then passing on draws the third particle to the second, thus displacing repulsive force, which drives the third and fourth particles further apart.

An impulse of repulsive force, on the other hand, first drives the second particle away from the first, displacing compulsive force from between them, and

forcing with the displaced compulsive force the second particle closer to the third. Next the impulse drives the third particle away from the second, thus displacing compulsive force between the second and third particles, and forcing the third and fourth particles closer together, and so on.

We thus see that when increments of compulsive force are propagated from any centre or source of force, the passage of the impulses outwards is marked by an expansive, or extensive action, followed by a compressive, or contractile action between the particles.

When increments of repulsive force, on the other hand, are propagated outwards, the passage outwards of the force impulses is marked by a compressive followed by an expansive action between the particles.

46. We have seen that when two blocks of wood of the same description and density, but of different sizes, were attached to a bar, and laid on the ground, under the same impulse of force, the larger block moved less rapidly and to a shorter distance than the smaller block did. The reason of this, plainly, is because the larger block contains a greater number of particles and has a larger surface in contact with the ground and the air; hence its particles are in contact with and transfer force to a larger number of particles of the ground and of the air; or because

being heavier in weight, and therefore having its particles in closer contact with the particles of the ground, the larger block is able to transfer force more readily than the smaller block. The effect of motion is, plainly, to bring the particles of the block into contact with fresh particles of the ground and of the air; and the greater the distance through which the block moves, the greater, plainly, will be the number of particles of the ground with which the particles of the block come in contact; hence it may happen that when the smaller block travels over the larger distance its particles may come in contact with the same number of particles of the ground as the larger number of particles of the larger block moving over a shorter distance come in contact with.

If the block of wood, when moving under the action of force horizontally over the surface of the ground, impinges against any obstacle, it will be stopped, if the obstacle is able to receive from the block the whole of the force under which the block is moving. The obstacle, having thus received the whole of the force under which the block was moving, will, then itself, move on, if it is unable to transfer to particles of other substances the whole of the force it has received; or if able to transfer the whole of the force it has received, the obstacle will remain motionless.

If an elastic solid body, moving under the action of a force, which it is unable to transfer to substances in contact with it, impinges against another elastic solid body in such a way that the direction of the force under which the body is moving is perpendicular at the point of impact to the surface of the solid impinged upon; then if the particles of the body impinged upon at the point of impact are able to transfer force to the other particles of the body and these in their turn to the particles of other substances in contact with the body, at the surface, as rapidly as force is received by them from the impinging body, there will be no motion in the body impinged upon; but instead that body will transfer to the impinging body the whole of the opposite force displaced from its particles by the force received from the impinging body; and the amount of the opposite force displaced being equal to the amount received, the impinging body, if it has transferred the whole of the force under which it was first moving, will move back after impact in the opposite direction, with force of the same amount as, but of the opposite kind to that under which it was moving before impact.

If under the same circumstances the particles of the body impinged upon are able to transfer, to the particles of other substances, only a part of the force which they receive from the impinging body; then

the body impinged upon will move under the portion of the force its particles were unable to transfer, in the same direction as the impinging body was moving before impact; whilst the body impinged upon will transfer to the impinging body an amount of the opposite force to that received from the impinging body, equal to that portion of the force received, which the particles of the body impinged upon were able to transfer to the particles of other substances in contact with them.

If the impinging body fail to transfer to the body impinged upon the whole of the force under which it was moving before impact, the portion of the force which remains untransferred may be reflected and may act after impact about a centre situated in the opposite direction to that in which the centre was situated about which it acted before impact.

If the surface of the body impinged upon is smooth, and if at the same time the direction of the force under which the impinging body is moving is not perpendicular to the plane of the surface of the solid impinged upon at the point of impact, then if the body is considered to be moving under the action of two forces, one acting in a direction perpendicular to the surface of the solid impinged upon at the point of impact, and the other, in a direction parallel to the surface of the solid at the point of impact, the impinging body will transfer to the body impinged

upon the whole of the force acting in a direction perpendicular to the surface of the solid impinged upon at the point of contact, retaining the force acting in a direction parallel to that surface, and receiving, from the body impinged upon, such an amount of the opposite force to that which it communicated to the body impinged upon, as will represent the amount of force displaced by that portion of the force which the particles of the body impinged upon are able to transfer away as rapidly as they receive it. The impinging body after impact will move off under the action of two forces: one, the force which acting in a direction parallel to the surface of the body impinged upon, was not transferred to that body; the other, a force acting in a direction perpendicular to the surface of the body impinged upon at the point of impact, displaced from the body impinged upon by the force transferred from the impinging to the impinged upon body, and transferred from the impinged upon to the impinging body. If the impinging and impinged upon bodies are perfectly elastic the impinging body will receive from the body impinged upon the same amount of force as, but of the opposite kind to, that which it transfers to the body impinged upon; hence after impact the impinging body will move away in a direction inclined away from the surface of the body impinged upon at the point of impact at the same

angle as the direction of the moving body was inclined before impact towards the surface of the body impinged upon at the point of impact.

If the impinging body fail to transfer by impact the whole of the force acting in a direction perpendicular to the surface of the body impinged upon at the point of impact the portion of the force untransferred may be reflected and may then act upon the body after impact in addition to the two forces mentioned above.

If the solid impinged upon is not perfectly elastic, the force received by it, from the impinging body, upon impact, will to a greater or less extent cause a permanent compression, or extension, in a part or in the whole of the particles of the body impinged upon and a proportionate reduction will be made in the quantity of force to be transferred by the particles of the body impinged upon.

47. If when a block of wood attached to a bar is moving over the surface of the ground under the action of a force the block passes off the ground on to some other surface, such as an iron, or a wooden, or a smooth ice surface, or on to a rougher surface than that of the ground on which it was moving before, we shall find that the block, which moved slowly over the ground, will under the same force applied in the same way move much more rapidly and to a much greater distance over the ice than it

did over the ground; we shall find also that in passing over the other surfaces the block will move more rapidly over some than it does over others. We have already seen that when under the same impulse of force applied in the same way one block of wood travels more rapidly and to a greater distance over the same surface of the ground than another, it is because the body which moves fast transfers force more slowly than the other body to the surface of the ground. When therefore we now find that the same body, under the same impulse of force applied in the same way, travels more rapidly, and to a greater distance, over some surfaces than over others, we may conclude that the reason is because some surfaces are better fitted than others to take force from a body moving over them; and that it is over the surfaces which are best fitted to take force from a moving body that the body moves with the least rapidity and to the shortest distance. We shall find that there are two descriptions of surfaces over which a body moves slowly, namely rough surfaces and adhesive surfaces. We can understand that when a body moves over rough surfaces, portions of the body may get entangled, or interlocked, with projecting portions of the rough surface and that then force will be transferred by the moving body to the rough surface by the impact and consequent grind-

ing away of the interlocked portions. In the case of the adhesive surface however the particles of the surface adhere or hold on to the particles of the body, until the force acting on the body tears the particles of the body away.

A moving body is said to transfer force to a surface over which it moves by Friction. Accordingly we see that just as there are two kinds of Force and two kinds of Motion, so also there are two kinds of Friction, namely, Friction by grinding or impact and Friction by rending or adhesion.

48. Hence we learn that Motion is simply a method of transferring force; and Friction and Impact are methods by which bodies at rest, or in motion, receive force from a moving body. This definition of Motion is plainly true whether motion produces change of position in a particle or merely contraction or expansion.

49. We have seen that particles of liquids and of gases besides adhering to each other adhere also to the surface particles of solids. It is clear also that, if the surface of a solid is rough, the particles of a liquid, or gas, through which any such solid with a rough surface may move, will become entangled, or interlocked with the surface particles of the solid; and therefore also that a solid body moving under compulsive or repulsive force through a liquid, or a gas, will transfer force to the particles

of the liquid or gas by friction of both kinds: also that particles of a liquid or gas in motion may transfer force either by impact, or by friction of both kinds, to the particles of a solid against which they impinge, or over which they pass; or to the particles of any liquid, or gaseous mass over, or through, which they pass.

We shall find that masses of a liquid, or of a gas, which impinge upon smooth solid surfaces, when moving in a direction, which is not perpendicular to the surface of the solid, are deflected in the same way that solid bodies, impinging on other solid bodies, under the same circumstances, are deflected. In this way the action of bends in pipes or channels may be explained.

A mass of liquid or of gas confined in a stout cylinder fitted with closely fitting pistons at either end will transfer force from one piston to the other in the same way that a solid bar transfers force.

50. We have hitherto dealt, except in the case of a body moving after impact with another body under the action of two forces, with motion under the action of a single force; but it is clear that bodies very often move under the action of the forces both of compulsion and repulsion acting at the same time, about different centres. Thus, for example, a projectile fired from a gun, whilst moving in a horizontal direction, under the action of the expansive,

or repulsive force, communicated by the explosion of gunpowder in the gun, is acted upon by gravity and moves under it in a vertical direction. Accordingly the projectile follows a curved path under the two movements. Again, when a ball attached to the end of a string is whirled round the head by a rotatory movement communicated to the hand; the ball impelled outwards by repulsive force, and, at the same time, prevented from moving in a straight line by compulsive force, acting about a different centre to that about which the repulsive force acts, describes under the action of the two forces a circular, or an elliptical path, according as the hand itself in rotating describes a circular or an elliptical path. It is noticeable that both repulsive and compulsive force reach the ball by the string.

If forces of attraction and repulsion acting about the same centre are communicated to the body at the same time the body will move under whichever of the two forces is the greater, following a straight path. Thus a projectile fired from a gun vertically up into the air rises until it has transferred the whole of the repulsive force communicated to it by the explosion of gunpowder in the gun, and then descends under the action of gravity.

50*a*. A mass of any form in motion will rotate if one side transfers force better than, and thus lags behind, the other side.

CHAPTER III.

CHEMISTRY AND CHEMICAL PHYSICS.

51. HAVING thus learnt generally that matter in all its forms is made up of different aggregations of certain extremely minute bodies or particles of some sixty or seventy different kinds differing from each other in that in each kind the particles have in the central atom existing in every particle a different capacity for receiving and a different method of distributing the forces of compulsion and repulsion from that which prevails in the central atoms of all the other kinds; but resembling each other in that, in all, the particles consist each of a central stable atom enveloped in an unstable sheath of compulsive and repulsive force, by which the particle at once holds on to and holds off all particles of every kind contiguous to it, drawing them nearer when impulses or increments of compulsive force reach it, and thrusting them further off when increments of repulsive force are received; resembling each other too in that, in all of them any particle is able according to its capacity to transfer

to, or to receive from any other particle contiguous to it increments either of compulsive, or of repulsive force, or in the event of any particle being unable to transfer increments either of the one force, or of the other to the particles contiguous to it, on one side, as rapidly as it receives itself like increments from particles contiguous to it on the other side, the particle, thus receiving greater increments of force than it is able to transfer, is able to move off to some other neighbourhood where either the increments of force which it receives are smaller, or the amount of force, it is able to transfer to contiguous particles, is larger; resembling each other, also, in that, in each kind for all the particles three states exist, namely, the solid, the liquid, and the gaseous, in the first of which compulsive force preponderates in the force sheath of the particle, and in the last repulsive force preponderates, whilst in the intermediate state the forces more nearly balance each other; and lastly resembling each other in that, in each of them, every particle is precisely similar in every respect to every other particle having the same amount of compulsive and repulsive force present in its sheath, so that the same grouping or arrangement as is adopted by any number of particles at any time will be adopted under the same circumstances by a similar number of the same kind of particles at any other time: we may now pro-

ceed to consider how far these conclusions harmonize with the teaching of Chemical Science.

52. We find then from chemistry that all matter organic, or inorganic, whether it exists in the solid, liquid, or gaseous state, can be resolved into between sixty and seventy distinct elementary substances: and that each of these elementary substances consists of an aggregation of exceedingly minute particles, all precisely similar to each other at the same pressure and temperature; but different from the particles of any other of the elementary substances.

We thus learn that there are as many different kinds of particles as there are different kinds of elementary substances: and that the different kinds of particles are named each after the elementary substance, which the particles of that particular kind form, when being dissociated from particles of every other kind, they are collected into masses. These elementary substances, sixty-four in number as far as is at present known, are divided into two classes, viz., metals and non-metals.

The chief of the non-metallic elementary substances are oxygen, hydrogen, nitrogen, chlorine, bromine, iodine, fluorine, carbon, sulphur, phosphorus, arsenic, boron, silicon.

The chief metallic substances are sodium, magnesium, calcium, potassium, iron, copper, lead, tin,

zinc, gold, silver, platinum, mercury, nickel, antimony, bismuth, manganese, aluminum.

Of these oxygen, hydrogen, nitrogen, and chlorine are at the ordinary temperature and pressure of the air gases; though, as Northmore first and subsequently Faraday, Cailletet, and Pictet (see Roscoe's "Chemistry," vol. i., p. 75, and vol. ii., part ii., p. 521) showed, they can all, by the application of pressure, which as we have seen is compulsive force acting directly, or after displacement, accompanied by the removal of heat, which, as we have seen, is repulsive force, be reduced to the liquid and solid state.

The remaining substances metallic and non metallic, except bromine and mercury, which are liquids, and fluorine, which cannot be dissociated, are all solid at the ordinary pressure and temperature of the atmosphere, though all, both liquids and solids, by the application of heat, or repulsive force, and the removal of pressure, or compulsive force, can be converted into the gaseous condition. So that there is no room for doubt that the elementary substances are all varieties of one type, and that further than this, there is no other difference between them, or between the particles of which each of them respectively is made up.

53. Now it is found that if masses of any two of the elementary gases, such as hydrogen and oxygen, or hydrogen and chlorine, are brought together, they

do not remain separate, as we might suppose th would, since oxygen is more than fifteen tim and chlorine is more than thirty-five times heavi than hydrogen; but the particles rapidly intermi and soon a mixture is formed, in which the particl of the two gases are uniformly distributed; tl particles of the denser gas with a larger amount compulsive force in their sheaths, take hold of tl particles of the lighter gas, and thus the particl of the two gases arrange themselves, in a series similar groups, throughout the mixture.

54. But though the particles of two gases inva ably intermix and arrange themselves in groups, th show, if they are elementary gases, no natural tenden to enter into the closer union implied in chemic combination, and the resulting gaseous mass remai a simple mixture, such as is the atmosphere of o earth, which is a simple mixture of nitrogen a oxygen gases. And there is a plain reason for thi for gases, as we have seen, have a very large propo tion of repulsive and a very small proportion compulsive force, in their force sheaths: and th unless, in some way or other, the particles receive supply of compulsive force to displace a portion the repulsive force in their sheaths and bring th central atoms closer together, they are unable draw close enough together to enter into chemi combination. Accordingly, in order to induce t

particles in a mixture of hydrogen and oxygen or of hydrogen and chlorine gases to enter into chemical combination, we must expose the mixture to the action of strong light, which, whether in the form of sunlight, or of rays from an incandescent solid, or of a flame, or of an electric spark, represents, as we shall see, an emission of displaced compulsive force; or we must subject the mixture to the action of a suddenly applied pressure, as in an explosion, in which compulsive force is violently displaced outwards; or we must bring the mixture in contact with some solid substance in a porous condition, such as spongy platinum, which by the action of the compulsive force in the sheaths of the surface particles in its pores, is able, in the manner explained in paragraphs 24 and 28 to condense the gases in its pores to a sufficient extent to effect combination. But since, in order to effect the chemical combination of gases, it is necessary to apply compulsive and displace repulsive force from the force sheaths of the particles we shall naturally expect when gases combine to find a great emission of heat or repulsive force take place. Thus we are not surprised to learn that it has been ascertained experimentally (*vide* Roscoe's "Chemistry," vol. i., p. 190) that, when one grain of hydrogen is burnt with oxygen, 34,000 heat units are evolved; whilst when a grain of iron is burnt in oxygen only 1576 heat units; or when a

grain of copper is burnt only 602 heat units are evolved. Or again to find that, when one grain of hydrogen is burnt in chlorine, to form hydrochloric acid, HCl, 23,000 heat units are evolved; whilst, when one grain of iron is burnt in chlorine, to form iron sesquichloride, Fe_2Cl_6, only 1745 heat units; and when one grain of copper is burnt to form copper chloride, $CuCl_2$, only 961 heat units are evolved.

Indeed, so great is the amount of heat, or repulsive force, displaced when the particles of two elementary gases combine, that we find, in some cases, the resulting compound is a liquid; thus the gases hydrogen and oxygen combine together and form water and the gases nitrogen and oxygen combine together to form nitrogen peroxide, which is a liquid at the ordinary atmospheric pressure and temperature.

55. Since the particles of solids contain a large proportion of compulsive force and a small proportion of repulsive force, and thus hold tightly together, we can understand how, while in order to induce the particles of two elementary gases to unite in chemical combination, it is necessary to supply them with compulsive force, so as to bring the particles closer together; on the other hand, to induce the particles of two elementary solids to unite in chemical combination, it is generally necessary to displace compulsive force from the particles and thus loosen their hold upon each other either by applying

repulsive force, by heating the solids, or by dissolving them in some liquid.

Indeed, so great is the amount of compulsive force lost when elementary solids combine together, that the resulting compound is sometimes a liquid; thus, when the elementary solids carbon and sulphur combine together, carbon disulphide, CS_2, is formed, which is a colourless liquid at the ordinary pressure and temperature of the atmosphere; again the elementary solids sulphur and phosphorus may combine together and form sulphur tetraphosphide, also a colourless liquid at the ordinary pressure and temperature of the atmosphere.

The formation of liquids by the combination of two solids contrasts in a remarkable way with the manner in which liquids are formed, as already pointed out, by the combination of two gases.

56. Liquid particles, being mobile, have the same tendency to intermix with the particles of other liquids, and form groups, that gaseous particles manifest; indeed so strong is the tendency towards group forming in liquids that in many cases a liquid is able when it comes in contact with solid masses to dissolve the masses of solid and to distribute the solid particles, plainly, in the group form uniformly throughout the liquid mass. However the grouping tendency, in the case of the liquid particles, is manifested to a more limited extent than it is in the

case of gaseous particles; since, in the case of liquids, it is generally manifested only between liquids and liquids or liquids and solids of the same type; thus water, which is a compound of hydrogen and oxygen particles, does not intermix with oil, which is a compound of carbon and hydrogen particles. The lowering of temperature, which takes place when a solid is dissolved in a liquid without chemical combination being set up, shows that the liquid transfers heat to the solid to loosen the hold of the particles of the solid upon each other. This is further shown by the fact that an increase of temperature usually enables the liquid more readily to dissolve the solid.

57. We have seen that elementary solids do not combine readily with other elementary solids, owing to the tight hold the particles have upon each other, from the large amount of compulsive force present in the sheaths of their particles; also that elementary gases do not combine readily with other elementary gases, owing to the large amount of repulsive force present in their envelopes. But since solids and gases viewed separately each possess in their particles, so to speak, an excess of the force required by the other to induce chemical combination, we shall be prepared to learn that particles of elementary solids combine more readily with particles of elementary gases than solids do with solids or gases with gases; and this indeed we find to be the

case, for many elementary solids, when exposed to the air commence at once to combine with the oxygen of the air. When a solid thus combines with a gas, we may assume naturally that the particles of the solid will lose compulsive force and the particles of the gas will lose repulsive force and that the resulting compound will be either a soft solid, a liquid, or a dense gas. Accordingly we find that when the elementary gas oxygen combines with any of the metals the compound is a soft solid, such as the common substance iron rust, which is a ferric oxide, Fe_2O_3, formed by the combination of oxygen particles with particles of the metallic elementary substance iron: also when the elementary gas chlorine combines with elementary solids, in many cases the resulting compound is a liquid, such for example as the substances sulphur monochloride, dichloride, and tetrachloride, which are all liquids, and which are combinations of chlorine, in different proportions, with the elementary solid sulphur: further, when the elementary gas hydrogen combines with any of the elementary solids, the resulting compound is generally a gas such as methane, or marsh gas, CH_4, a compound of hydrogen with carbon, or sulphuretted hydrogen, H_2S, a compound of hydrogen with sulphur.

Since, whenever elementary solids combine with gases, compulsive force is, as we have seen, lost by the particles of the one and repulsive force is

lost by the particles of the other, we may expect to find, if light is really compulsive and heat is repulsive force, that while solids are thus combining with gases an evolution of light and heat will take place. And we find, indeed, that when elementary solids and gases energetically combine together, an evolution of light and heat in a very marked degree takes place; as, for example, when the elementary solids carbon, phosphorous, sulphur, or iron are burnt in oxygen, a brilliant light and a large amount of heat mark the progress of the combustion. The fact that iron and other substances may be slowly oxidized without any sensible evolution of light or heat occurring, in no way invalidates the accuracy of our conclusions; for we can understand that the same amount of light or heat, which, if evolved rapidly, will make a great impression upon our senses, may be absolutely inappreciable if it is evolved so slowly that its disengagement covers a long period.

58. We may now for a while study critically, in the way first pointed out by Dalton, some of the various combinations, which particles of different kinds form with one another.

We find then that when particles of nitrogen combine with particles of oxygen one or other of the following combinations will be formed:—

1st. Nitric oxide, NO, may be formed, in which

about 14 parts by weight of nitrogen are combined with 16 parts by weight of oxygen.

2nd. If additional oxygen is added to the nitric oxide; the 14 parts by weight of nitrogen will then take 32 or 16 + 16 parts by weight of oxygen, and the substance nitrogen peroxide will be formed.

3rd. Nitrous oxide may be formed, in which 28 or 14 + 14 parts of nitrogen are combined with 16 parts by weight of oxygen.

4th. Nitrogen trioxide may be formed, in which 28 or 14 + 14 parts of nitrogen are combined with 48, or 16 + 16 + 16 parts by weight of oxygen.

5th. Nitrogen pentoxide may be formed, in which 28, or 14 + 14 parts of nitrogen are combined with 80 or 16 + 16 + 16 + 16 + 16 parts of oxygen.

We thus see that 14 parts by weight of nitrogen may combine either with 16, or 16 + 16 parts by weight of oxygen, and that 14 + 14 parts of nitrogen may combine with 16 or 16 + 16 + 16, or with 16 + 16 + 16 + 16 + 16 parts of oxygen; also that the proportion by weight of nitrogen is either 14 or twice 14, whilst the proportion by weight of oxygen is either 16 or twice or three times or five times 16, i.e. always 16 or a multiple of 16.

Again, when sulphur combines with oxygen, we find that one of the three following compounds is formed:—

1st. Sulphur dioxide, SO_2, in which 32 parts by

weight of sulphur combine with 32 or 16 +
parts by weight of oxygen.

2nd. Sulphur trioxide, SO_3, in which 32 part
weight of sulphur combine with 48, or 16 + 16 +
parts by weight of oxygen.

3rd. Sulphur sesquioxide, S_2O_3, in which 6
32 + 32 parts by weight of sulphur combine wit
or 16 + 16 + 16 parts by weight of oxygen.

Here again we notice that the proportion
weight in which oxygen combines with sulphu
always a multiple of the number 16.

So also when hydrogen combines with ox
two compounds may be formed, viz. :—

1st. Water, H_2O, in which 2, or 1 + 1 parts
weight of hydrogen combine with 16 parts
weight of oxygen.

2nd. Hydrogen peroxide, H_2O_2, in which 2
1 + 1 parts by weight of hydrogen combine wit
or 16 + 16 parts by weight of oxygen.

Here once more we find oxygen combining
weight in a proportion, which is represented
16, or a multiple of 16.

So too when hydrogen combines with nitro
it forms one compound, ammonia NH_3, in w
14 parts by weight of nitrogen combine with
1 + 1 + 1 parts by weight of hydrogen.

Here we notice that hydrogen and nitrogen
bine together in a proportion by weight represe

in the case of the one, by a multiple of 1, and in the case of the other, by the number 14; whilst, as we have already seen, the proportion by weight in which hydrogen combines with oxygen is also a multiple of 1, and the proportion by weight in which nitrogen combines with oxygen is represented by 14 or a multiple of 14.

So likewise, when hydrogen combines with sulphur, two compounds are formed, viz.:

1st. Sulphuretted hydrogen, H_2S, in which 2, or 1 + 1 parts by weight of hydrogen combine with 32 parts by weight of sulphur.

2nd. Hydrogen persulphide, H_2S_2, in which 2, or 1 + 1 parts by weight of hydrogen combine with 64 or 32 + 32 parts by weight of sulphur. Here likewise we find sulphur combining with hydrogen in the same proportion by weight, viz. 32, or a multiple of 32, in which it combines with oxygen; and hydrogen also combining in the same proportion by weight, viz. a multiple of 1, as it combines with oxygen. If, in the same way, we follow oxygen through the many thousands of compounds, which it forms, we shall find that the proportion by weight in which it combines is always 16, or a multiple of 16; similarly we shall find that in all the compounds, which hydrogen forms, the proportion by weight in which it is combined is always 1, or a multiple of 1; similarly the proportion by

weight in which nitrogen combines is always 14, or a multiple of 14, and the proportion by weight in which sulphur combines is always 32 or a multiple of 32. Likewise each of the other elementary substances has a combining weight peculiar to itself, invariably adhered to whether in the smallest fragment, or in the largest mass.

And not only so, but when one of these elementary substances displaces another, in a compound already formed, the proportion of the displacing substance, taking the room of the substance displaced, is always the same as the proportion in which the displacing and the displaced substances combine together: thus when oxygen replaces hydrogen in a quantity of marsh gas, CH_4, in which 12 parts by weight of carbon are combined with 4 or 1 + 1 + 1 + 1 parts by weight of hydrogen, it is found that 32 or 16 + 16 parts by weight of oxygen (which is the precise weight of oxygen required to combine with the 4 or 2 + 2 parts of displaced hydrogen in order to form water, H_2O) will take the place of the 4 parts of hydrogen and the gas will be converted into carbonic acid gas CO_2.

In this and other ways it can be shown with certainty that the elementary gases oxygen and hydrogen consist each of an aggregation of particles, and that an oxygen particle weighs 16 times

as much as a hydrogen particle; similarly that nitrogen and sulphur, as well as all the other elementary substances, consist each of an aggregation of particles, and that a nitrogen particle weighs 14 times as much, and a sulphur particle 32 times as much as a hydrogen particle, and so on, the particles of each elementary substance having a weight peculiar to itself.

It can also be shown in this way that every hydrogen particle weighs the same as every other hydrogen particle, and every oxygen particle the same as every other oxygen particle, and every sulphur particle the same as every other sulphur particle, and so on. An oxygen particle indeed is not exactly 16 times as heavy nor is a sulphur particle exactly 32 times as heavy as, nor a nitrogen particle exactly 14 times as heavy as a hydrogen particle; but these numbers are close enough to the real numbers for all practical purposes.

59. The weight of a particle is the quantity of compulsive force a particle receives from the earth as gravity, in excess of the quantity it is able to transfer to contiguous particles; thus the weight of a particle affords an index of the size of the central atom of the particle; the heavier particle being the one with the larger central atom, as we shall see further on.

We have seen that the particles of two gases,

which come into contact, intermix and arrange themselves in a series of groups; also that the particles of two liquids, which come into contact; as well as those of a solid intermixed with the particles of a liquid, by the process of solution, frequently arrange themselves in groups; it will now be apparent that, in compounds, the particles are arranged in groups, each group having the same number of particles, and the same proportion, of the several kinds of particles of which the compound is made up as every other group in the compound has. And when then we meet with such a compound, for example, as nitrogen peroxide, in which 14 parts by weight of nitrogen are combined throughout every part of the mass with 16 + 16 parts by weight of oxygen, knowing that the combining weight of a particle of nitrogen is 14 and that of a particle of oxygen is 16, we shall understand that nitrogen peroxide is a substance made up of an aggregation of groups of particles each containing one nitrogen and two oxygen particles. Similarly sulphur dioxide, in which, throughout, 32 parts by weight of sulphur are combined with 16 + 16 parts of oxygen, will, since the combining weight of sulphur is 32, be seen to be a substance made up of groups of particles each containing one ...hur united to two oxygen particles. Similarly ...r, in which 1 + 1 parts by weight of hydrogen

are combined with 16 parts by weight of oxygen, will, since the combining weight of hydrogen is 1, be seen to be made up of groups of particles in which two hydrogen are united to one oxygen particle. So also ammonia, in which, as we have seen, 14 parts by weight of nitrogen are combined with 1 + 1 + 1 parts of hydrogen, will be seen to consist of groups of particles in each of which a nitrogen particle is united to three hydrogen particles. Also hydrochloric acid, HCl, in which 1 part by weight of hydrogen is combined with 35·5 parts by weight of chlorine will, since 35·5 represents the combining weight of chlorine, be seen to consist of groups of particles in which one hydrogen is united to one chlorine particle.

60. But now, as Gay Lussac first showed, gases besides combining by weight combine also by volume; and although, as we have seen, 1 part by weight of hydrogen combines with 35·5 parts by weight of chlorine to form hydrochloric acid, it is necessary also, in order to form hydrochloric acid, that equal volumes of hydrogen and of chlorine should be taken. When two volumes of hydrogen and chlorine thus combine two volumes of hydrochloric acid are obtained; showing that the gases occupy the same volume after as they did before combination took place. Now since in the formation of hydrochloric acid every particle of chlorine

takes to itself a particle of hydrogen, it follows that there must be before combination takes place as many hydrogen particles as there are chlorine particles. But before combination takes place the volume of hydrogen must be, as we have seen, equal to the volume of chlorine; it therefore follows that a chlorine and a hydrogen particle must have the same volume. But since a chlorine particle is 35 times as heavy as a hydrogen particle and must therefore have a proportionately greater amount of compulsive force present in its force sheath and must have the central atoms of its particles proportionately closer together, it appears almost certain that the central atoms of chlorine particles are larger than those of hydrogen particles.

On the other hand, in the formation of water, in which the groups consist, as we have seen, of two particles of hydrogen united with one particle of oxygen, it is necessary to take three equal volumes of gas, namely, two of hydrogen and one of oxygen: but now, two volumes only and not three volumes of steam or gaseous water will be obtained; or two-thirds of the volume of gas consumed; or the same quantity as if one volume of oxygen had been simply mixed with one volume of hydrogen. From this, since, in forming water, every oxygen particle, as we have seen, takes to itself two hydrogen particles, and in order that combination may take place twice as

many hydrogen particles must therefore be provided, as there are oxygen particles, it is apparent that before combination takes place a hydrogen particle has the same volume as an oxygen particle; but after combination has taken place the two hydrogen particles then occupy only the same volume, as a single hydrogen particle occupies when uncombined, or as the single oxygen particle occupies in each of the groups of which water is made up. Since an uncombined particle of hydrogen has the same volume as a particle of oxygen, and yet the oxygen particle is, as we have seen, sixteen times as heavy as the hydrogen particle, it seems clear that the central atom of an oxygen must be proportionately larger than the central atom of a hydrogen particle.

Again, in the formation of ammonia, NH_3, in which the groups of particles consist of one particle of nitrogen united with three particles of hydrogen, it is necessary to take four equal volumes of gas, of which one volume must be nitrogen and three volumes hydrogen: but only two and not four volumes of ammonia will be obtained; or, one-half of the volume of gas consumed; or the same volume, as would have been obtained, if one volume of nitrogen and one of hydrogen had been simply mixed together. From this it is apparent that a particle of hydrogen before combination takes place occupies the same volume as a particle of nitrogen;

but after combination has taken place three hydrogen particles then occupy only the same volume as a single hydrogen particle, when uncombined occupies, or as the single nitrogen particle occupies in each of the groups of which ammonia is made up.

61. We have seen that, when two particles of hydrogen combine with a particle of oxygen to form one of the groups of particles of which water is made up, the two particles of hydrogen are condensed to the same volume as a single particle of hydrogen occupies when uncombined; also that when three particles of hydrogen are combined with a single particle of nitrogen to form one of the groups of particles of which ammonia is made up the three particles of hydrogen are condensed to the same volume as a single particle of hydrogen occupies when uncombined; we shall perhaps see further that the increased amount of condensation, thus noticeable with the groups containing the larger number of particles, explains the reason why, when, from the combination of an elementary solid with an elementary gas, a substance is formed which at the ordinary pressure and temperature of the atmosphere, is in the liquid or in the gaseous state and which has, in the groups of particles of which it is made up, only a small number of particles of the gas combined with particles of the solid, the addition of a further quantity of the gas whereby

the proportion of gaseous particles in each group of particles is increased, it is that the compound sometimes assumes at the ordinary pressure and temperature of the atmosphere the solid form, in place of approximating more and more nearly to the nature of its gaseous constituent, as we might imagine from the larger proportion of the gas in its composition, it would do. Thus for example when chlorine is added to selenium monochloride, Se_2Cl_2, a brown liquid having, in each of its groups of particles, two particles of the elementary solid selenium combined with two particles of the elementary gas chlorine, the effect is to convert the monochloride into the tetrachloride, which is a white solid body made up of groups of particles, each having one particle of selenium combined with four particles of chlorine (Roscoe's "Chemistry," vol. i., p. 359). Again if oxygen, in presence of a piece of heated spongy platinum, is added to sulphur dioxide, which is a colourless gas made up of groups of particles, each having one atom of sulphur combined with two atoms of oxygen, the gaseous sulphur dioxide is converted into the solid sulphur trioxide made up of groups of particles each having one particle of sulphur combined with three particles of oxygen.

62. It may be here remarked that the gas sulphur dioxide is specially interesting because, as Tyndall

has shown, when a beam of sunlight is passed through a long tube filled with this colourless gas a white cloud composed of sulphur particles and particles of the solid sulphur trioxide, makes its appearance (Roscoe's "Chemistry," vol i., pp. 306—311). The formation of the cloud seems to indicate plainly that light is a compulsive force since the beam of sunlight is able so far to condense the oxygen particles in a portion of the gaseous sulphur dioxide as to make them no longer able to hold the same number of particles of sulphur as before; and is thus able, as it were, to squeeze out a portion of the sulphur, and to convert a portion of the gaseous sulphur dioxide into the two solids, sulphur and sulphur trioxide, of which the cloud is formed.

63. However, the effect of increasing the proportion of gaseous particles in groups of particles, in which particles of an elementary solid are combined with particles of an elementary gas, is, when, with a small proportion of gaseous particles in its groups, the substance is a solid, the opposite to that which, as we have seen, is produced, when, with a small proportion of particles of a gas in its groups, the substance is a gas or a liquid, since the solid is frequently converted into a liquid or into a gas, instead of the liquid or the gas being converted into a solid, and this is more frequently noticeable with hydrogen compounds, or in compounds of oxygen,

or chlorine with a metal, than in compounds of oxygen with a non-metal. Thus hydrogen tetraphosphide, P_4H_2, in which the groups are composed of four particles of phosphorus combined with two of hydrogen, is a solid: hydrogen diphosphide P_2H_4, in which the groups are composed of two particles of phosphorus combined with four particles of hydrogen, is a liquid: whilst hydrogen phosphide, PH_3, in which the groups are composed of one particle of phosphorus combined with three of hydrogen, is a gas (Roscoe's "Chemistry," vol. i., p. 474).

Again, vanadium dichloride, in which the groups are composed of one particle of the metal vanadium combined with two of chlorine, and vanadium trichloride, in which the groups are composed of two particles of vanadium combined with six of chlorine, are both solids; whilst vanadium tetrachloride, in which the groups are composed of one particle of vanadium combined with four particles of chlorine, is a liquid (Roscoe's "Chemistry," vol. ii., part 2, p. 294).

Again, manganese dioxide, MnO_2, in which the groups are composed of one particle of the metal manganese combined with two particles of oxygen, is a solid; whilst manganese heptoxide, Mn_2O_7, in which the groups consist of two particles of manganese combined with seven particles of oxygen,

is a liquid (Roscoe's "Chemistry," vol. ii., part 2, p. 5).

64. We have seen that in hydrochloric acid the groups are composed of one particle of hydrogen combined with one particle of chlorine; we find also that besides those of chlorine the particles of some other elementary substances such as bromine and iodine are able to take to themselves only a single particle when combining with hydrogen; thus we have hydrobromic acid, in which the groups consist of a single particle of bromine united to a single particle of hydrogen; and hydriodic acid, in which the groups are made up of a single particle of iodine united to a single particle of hydrogen. We find also that there are other elementary substances, such as oxygen and sulphur, whose particles cannot unite singly with less than two particles of hydrogen; thus oxygen combining with hydrogen forms water, H_2O, in which the groups consist of a single particle of oxygen united to two particles of hydrogen; and sulphur combining with hydrogen forms sulphuretted hydrogen, H_2S, in which the groups are made up of a single particle of sulphur united to two particles of hydrogen. No compound is known in which the groups are made up of single particles of oxygen united to single particles of hydrogen; nor is any known in which the groups are made up of single particles of sulphur united to single par-

ticles of hydrogen, though the compound hydrogen peroxide, H_2O_2, is known, in which the groups consist of two particles of oxygen united to two particles of hydrogen; and the compound hydrogen persulphide is known, in which the groups consist of two particles of sulphur united to two particles of hydrogen. Hence we see that there must be some difference between the force sheaths of particles of the chlorine and bromine type and those of particles of the oxygen and sulphur type to account for the fact, that while single particles of elementary substances of the one type are satisfied with single particles of hydrogen, single particles of elementary substances of the other type must get two particles of hydrogen.

Again, there are other elementary substances, such as nitrogen and phosphorus, whose particles cannot unite singly with less than three particles of hydrogen; thus we have the compound ammonia, NH_3, in which the groups consist each of a single particle of nitrogen united to three particles of hydrogen. Again, we have the compound phosphuretted hydrogen, in which the groups consist of a single particle of phosphorus united to three particles of hydrogen.

Again, there are other elementary substances, such as carbon, whose particles cannot unite singly with less than four particles of hydrogen;

thus we have the compound marsh gas in which the groups consist, each, of a single particle of carbon united to four particles of hydrogen, and no compound is known in which the groups consist of a single particle of carbon united to a smaller number than four particles of hydrogen; though we have ethine, in which the groups consist, each, of two particles of carbon united to two particles of hydrogen; and ethylene in which the groups consist, each, of two particles of carbon united to four particles of hydrogen; and ethane, in which the groups consist, each, of two particles of carbon united to six particles of hydrogen.

We thus obtain four classes, in which elementary substances are grouped according to the smallest number of hydrogen particles with which their particles can singly unite.

But if in place of taking compounds with hydrogen we take compounds with chlorine, another substance of the same class as hydrogen, we that many substances form with chlorine compounds, in which their particles unite with, in each case, a different number of s of chlorine; thus tungsten combines lorine to form, firstly, tungsten dichloride, , in which the groups consist, each, of a single cle of tungsten united to two of chlorine; ndly, to form tungsten tetrachloride, WCl_4, in

which the groups consist, each, of a single particle of tungsten united to four particles of chlorine; thirdly, to form tungsten pentachloride, WCl_5, in which the groups consist, each, of a single particle of tungsten combined with five particles of chlorine; and lastly, to form tungsten hexachloride, WCl_6, in which the groups consist each of a single particle of tungsten united to six particles of chlorine (Roscoe's "Chemistry," vol. ii., part 2, pp. 202-204). Again, iodine combines with chlorine to form, firstly, iodine monochloride, ICl, in which the groups consist, each, of a single particle of iodine united to a single particle of chlorine; and secondly, to form iodine trichloride, in which the groups consist, each, of a single particle of iodine united to three particles of chlorine. Hence besides classifying elementary substances according to the smallest number of particles of some other elementary substances, with which their particles respectively can singly unite; we may also classify them according to the greatest number of particles of some substance such as chlorine, with which their particles singly can unite.

We have seen that in tungsten hexachloride, the groups are composed of a single particle of tungsten united to six particles of chlorine (we shall find no compound in which the groups consist of a single particle of any substance united to more than six

particles of any other substance. And this plainly is an important point to notice, since it may help us in ascertaining the number of bonds or points of attachment in the force sheaths of particles). We shall find other elementary substances forming compounds, such as phosphorus pentachloride, PCl_5, or antimony pentachloride, $SbCl_5$, in which the groups consist of single particles of phosphorus, or of antimony, united with five particles of chlorine.

We shall find other elementary substances, such as manganese, vanadium, titanium, &c., whose particles, singly, are not able to unite with more than four chlorine particles.

Proceeding in this way we may obtain six classes, in one or other of which all elementary substances can be classed; the substances being named in accordance with the atomic theory monads, dyads, triads, tetrads, pentads, or hexads, according as [illegible]ey come respectively in the first, second, third, [illegible]rth, fifth, or sixth of these classes; monads [illegible]ing those elementary substances, such as hydro[illegible]nd chlorine, whose particles unite singly with [illegible] particles of other monads, and hexads those [illegible] particles, singly, can unite with six monad [illegible]ies.

[illegible] Now if we turn to Figs. 4 and 5, p. 53, and con[illegible]r the shaded portions in those figures to [illegible]resent in the force sheaths of the particles, those

portions which act as ties to connect the central atoms of the particles with the central atoms of contiguous particles, we shall be able to understand how completely the teaching of the atomic theory, indicating, as it does, the broad fact that particles have on each side of them, each according to its kind, a definite number of ties, by which it is enabled to hold on to a definite number of other particles contiguous to it, is in agreement with the arrangement indicated in Figs. 4, 5, and 6, in which the particle is shown as being endued with a force sheath of regular form divided up, in a regular way, into compulsive force, or holding on portions or ties, and into repulsive force, or holding off portions or struts. For if we find that while, on the one hand, single particles of some of the elementary substances are able to unite with or take to themselves not more than six monad particles (and, as already pointed out, no single particle of any elementary substance is able to unite with more than six particles of another elementary substance); while again single particles of other elementary substances are able to unite with, or to take to themselves not more than five of the same monad particles; while again single particles of others are able to take not more than four; those of others not more than three; those of others not more than two; and lastly, while those of some

are not able to unite with more than one particle—on the other hand, single particles of some elementary substances are not able to unite with less than four monad particles; and those of others are not able to unite with less than three; and those of others with not less than two monad particles: and we find also, that while generally single monad particles can alone replace, in any compound, other single monad particles; two monad particles are equivalent to and can replace one dyad particle; three monad particles are equivalent to and can replace one triad particle, and four monad particles are equivalent to and can replace one tetrad particle (Roscoe's "Chemistry," vol. i., p. 96), the inference is clear that definite portions of the force-sheaths of all particles, or, what is the same thing, of the surfaces of the central atoms of particles are occupied by the compulsive force by which particles hold on to each other, and that these portions, though they can be enlarged or reduced, can only be so enlarged or reduced within certain limits. And when then we find that single particles of any substance are able to make several combinations with particles of some other substance, in each of which the single particles are united to a different number of particles of the other substance, we may understand that the combination, in which the groups are made up of the smallest number of

particles, is effected when the single particles find a deficiency of the other particles, and therefore under unfavourable circumstances; and that the combination, in which the groups are made up of the highest number of particles, is effected under specially favourable circumstances, by which the compulsive force portions of the envelopes of the particles, which combine, are extended to their fullest limit. Thus, neither the combination, in which the groups contain the smallest number of particles, nor that in which they consist of the highest number of particles, is a stable one; for as soon as the unfavourable, or the specially favourable circumstances pass away, a change takes place. Thus, with a deficiency of oxygen, nitrogen combines with oxygen to form nitric oxide, NO, in which the groups consist each of a single nitrogen united to a single oxygen particle; but, as soon as nitric oxide is exposed to the air, each of the groups takes an additional particle of oxygen, and the nitric oxide, NO, is converted into nitrogen tetroxide, NO_2, in which the groups consist of a single particle of nitrogen united to two particles of oxygen. Again, by withdrawing from anhydrous nitric acid, HNO_3, the elements of water, it is possible to obtain nitrogen pentoxide, N_2O_5, (Roscoe's "Chemistry," vol. i., p. 413), in which the groups consist, each, of two nitrogen particles united to five oxygen par-

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ticles; but nitrogen pentoxide decomposes at a temperature between 45° and 50° C. This conclusion is strengthened by the fact, already noticed, that when a monad particle, such as one of chlorine, unites itself to a particle of hydrogen, no contraction of volume, in either particle, takes place; but when, however, a dyad particle of oxygen seizes and takes to itself two particles of hydrogen, the two particles of hydrogen are condensed to the volume of the dyad oxygen particle, or to that of a single particle of hydrogen, when uncombined; whilst, when a triad nitrogen particle seizes and takes to itself three hydrogen particles, the three particles are condensed to the volume of the nitrogen particle or to that of a single hydrogen particle when uncombined.

66. The condensation of hydrogen particles, by oxygen or nitrogen particles with which they combine, exhibits in a striking way the drawing together of particles which, as already noticed, takes place, accompanied by a displacement of repulsive force, when particles of two elementary gases combine, or when an elementary gas combines with an elementary solid.

It is to condensation, denoting, as it does, an increase of compulsive force, that the superior activity, in combining, of ozone, which is oxygen condensed, by the passage of the electric spark through

oxygen or in some other way, from three volumes into two volumes (Roscoe's "Chemistry," vol. i., p. 196), over oxygen, is due. The fact that ozone, which is one of the most powerful oxidizing agents known, attacking at once and destroying organic substances, such as caoutchouc, paper, &c. (Roscoe, vol. i., p. 201), should lose much of its oxidizing power and be converted into ordinary oxygen gas, as soon as its volume is expanded by the application of heat, or repulsive force, and the consequent displacement of compulsive force, is specially noteworthy. And this fact becomes more especially noteworthy, when taken in connexion with the fact that a piece of tinder can be lighted in a cylinder, by suddenly compressing the air in the cylinder by the aid of a piston ("Recent Advances in Physical Science," p. 9), showing that the particles of oxygen in the air, when thus condensed, are able to combine with the carbon particles in the tinder, heated by repulsive force displaced from the compressed air, with sufficient energy to set up combustion.

The fact that a piece of spongy or porous platinum is able, in the way already indicated in paragraph 54, to condense hydrogen and oxygen particles in its pores to such an extent as to bring about combination between them, should also be remembered.

67. We have seen that, when particles of two

elementary gases, or of an elementary gas and an elementary solid combine, a drawing together of the lighter gaseous particles, with a displacement of repulsive force, must take place, and that, when particles of two elementary solids combine, or an elementary solid combines with an elementary gas, and even when a dense elementary gas combines with a light one, a separation, or thrusting apart of the solid particles one from another, involving a loss of compulsive force, must take place before the drawing together which constitutes chemical union can be effected. We can therefore understand that two particles in a compound are, in many cases, brought much closer to each other than they can ever approach to other particles, whether of the same kind as themselves or of a different kind, in any state, whether solid, liquid, or gaseous, when existing in the pure or uncombined; and that it is to the shortness of the distance through which the compulsive force, which binds two particles united in chemical combination together, acts, that the connexion between the particles becomes so strong that it is able to endure through changes which convert the compound from a solid to a liquid, and from a liquid to a gas. The loss of compulsive force in the mass as a whole, which, as we have seen at paragraph 57 takes place when a solid combines with a gas, is not incompatible with the fact

of the particles of the gas being by the process of combination brought closer to the particles of the solid than the particles of the solid are brought to one another, in the process of solidification; for we can understand that though, in the compound, particle may be nearer to particle in the groups, yet group may be further from group, than, in the solid, particle is from particle. In this way we can understand how in the formation of hydrochloric acid, as described in paragraph 60, a hydrogen particle may be brought closer to a chlorine particle than a hydrogen particle is to a hydrogen particle in a mass of hydrogen, or a chlorine particle to a chlorine particle in a mass of chlorine, and yet group may be further from group in hydrochloric acid than particle is from particle in a mass of hydrogen or of chlorine, and so, though no change of volume may take place in the formation of hydrochloric acid, a displacement of repulsive by compulsive force may take place. At the same time it must be remembered that there are combinations which, though they are possible in the solid state, are not possible in the gaseous state, and therefore the effect of the greater amount of compulsive force present in the solid state is by no means to be overlooked.

We must remember that the state of chemical combination is forcibly brought about, and does not

consist in the mere grouping of particles together in order, such as takes place when particles of different liquids or gases form by diffusion a simple mixture; and then if at the same time we remember that the action of a force is inversely proportional to the square of the distance at which the force acts, we shall have little difficulty in understanding how if particles, united in chemical combination, are drawn much closer together than particles in the solid state are, the ties, which hold the particles in a pair or in a group of particles together in chemical union should last, even though the ties which hold the pair or group to other pairs or groups contiguous to them in a solid mass are ruptured.

68. Pairs or groups of particles, when united in chemical combination, thenceforth act and move just as single particles do; thus they, when in the gaseous state or in the liquid state, diffuse, or mix up, and form groups with other gases, or liquids, with which they come in contact; or dissolve solid substances [illegible] ticles of the elementary gases, or liqu[illegible] cooled down by the abstraction [illegible] to pressure, they [illegible] or solid form; [illegible] subjected to [illegible] of pressure, [illegible] form just as

particles of elementary substances do; or again, they combine with the groups of other compounds, forming fresh compounds, just as we have seen particles of one elementary substance combine with particles of other elementary substances.

69. But if, when in chemical combination, particles of one substance are so closely united with particles of another substance that the united group thenceforth is enabled to act and move as a single particle, it will be plain that the individual properties and action of the particles composing the group will have been merged into those of the group; and that group action and group properties will be substituted for the individual action and individual properties of the several particles composing the group. Thus for example, air is a mixture of the two colourless odourless gases nitrogen and oxygen; and air, like the two gases of which it is made up is practically colourless and odourless too, and will remain so as long as the two gases in it remain simply mixed together: but if a series of electric sparks are passed through a quantity of air and a portion of the nitrogen in the air is made by the compulsive force of the electric spark to combine [illegible] a portion of the oxygen to form the compound [illegible]gen peroxide NO_2, in which the groups consist [illegible] a single particle of nitrogen united to two [illegible] of oxygen, the colourless odourless air will

be transformed into nitrogen peroxide, which in the gaseous form is a brown vapour having a very unpleasant smell, and at the ordinary temperature of the atmosphere, is a yellow-coloured liquid. Again, carbon ordinarily exists in the form of a black opaque solid, whilst sulphur ordinarily exists in the form of a yellow opaque or semi-transparent solid, and neither carbon nor sulphur have any odour; but when carbon combines with sulphur; the compound carbon disulphide CS_2 is formed, in which the groups consist each of a single particle of carbon united to two particles of sulphur; and this carbon disulphide is a colourless liquid having a sweet smell. In both these cases we see that the properties of the groups are totally different from those of any of the individual particles of which the groups are composed.

70. In order to show how very closely the action of groups of particles in compounds corresponds with that of single particles in elementary substances, we may point to cyanogen, a compound of carbon and nitrogen, in which the groups consist, each, of two particles of carbon united to two particles of nitrogen, and which combines with hydrogen to form hydrocyanic acid, in which the groups consist, each, of one of the groups of which cyanogen is made up united to a particle of hydrogen, just as in hydrochloric or hydriodic acid the groups are formed

by the union of a single particle of chlorine or of iodine combined with a single particle of hydrogen. We may point also to other compounds of cyanogen, such as the cyanide of mercury, $Hg(CN)_2$, in which the groups consist each of two of the groups of which cyanogen is made up united to a single particle of mercury. So also we find ammonia, NH_3, in which the groups consist, each, of a particle of nitrogen united to three particles of hydrogen, forming compounds, such as the carbonate, sulphate, or nitrate of ammonium, corresponding to the carbonates, sulphates, and nitrates formed by many of the metals.

71. The compounds formed by combinations of compounds may be further combined, and thus substances made up of groups of particles united together in a very complex way may be obtained; but into the changes and interchanges by which these substances are obtained, it is not necessary here to go, the general principles by which compounds are formed being plainly indicated in the combinations, which take place between the particles of elements, and which have already been considered.

72. We have seen that the particles, in the groups of particles, of which compound substances are made up, are united together by compulsive force; it is plain then that if we wish to separate two substances which have combined together we must displace the

compulsive force by which the particles of the substances are held together: and as compulsive force can only be displaced by repulsive force, some method of applying repulsive force to the compound must be employed. Accordingly, to dissociate substances in combination the compound must either be exposed to a very high temperature at which compulsive force practically ceases to be evolved by displacement, and the emission is one of unmixed repulsive force, or repulsive force must be applied by a current of electricity, with which, as will be better seen hereafter, repulsive force is liberated from one pole, viz. the positive pole. There is a way, however, of dissociating one of the substance in a compound which is often employed, and that is by displacement, or by bringing the compound in contact with some substance which has a greater affinity for the other substance, or substances, in the compound than the substance to be displaced has: the process of displacement is assisted if necessary by the application of heat.

When a substance has been displaced from a compound, its particles for a time have still about them a considerable amount of the compulsive force by which they were held in combination, and are consequently in this state, which is called the nascent state, more ready than at other times to combine with the particles of other substances: thus oxygen

in the nascent state occurs in the form of ozone, which, as already stated, is by far the most active form in which oxygen is found.

73. The process of crystallization has been discussed already at paragraph 36; and it is not necessary to enter further into the subject here, except to point out that the emission of light visible, in some cases, at the moment a crystal is formed, if the process of the formation of crystals is watched in a dark room (see "La Lumiere," by M. Edmond Becquerel, p. 39), may perhaps be explained on the assumption that the sudden consolidation of particles, which takes place when luminous effects are noticed, liberates a sufficient amount of repulsive force to displace a certain quantity of compulsive force in some of the particles, whether solid, liquid, or gaseous, which intervene between the crystal and the eye. In the same way too we may assume that the flash, which is noticed sometimes when two gases combine explosively under the action of compulsive force, and the pale flame visible when two gases combine by the action of compulsive force, are due to compulsive force displaced from the air particles between the eye and the point where the combination of the gases is effected, by the action of the large amount of repulsive force liberated by the combination of the gases.

73. The fact that marsh gas, in which the groups

consist, each, of a single particle of carbon united to four particles of hydrogen, burns in air with a non-luminous flame; whilst olefiant gas, in which the groups consist, each, of two particles of carbon united to four particles of hydrogen, burns with a luminous flame, can perhaps be explained on the assumption that a greater amount of compulsive force, than is required by the hydrogen particles, is displaced from the two carbon particles in each group of particles in the olefiant gas. If, however, as in the Bunsen burner, a large amount of air is mixed with the gas, so as to supply sufficient oxygen to effect the complete combustion of the whole of the hydrogen particles; then the whole of the compulsive force displaced from the carbon particles will be employed in effecting the combination of the increased amount of hydrogen particles, which are burnt, and the flame, though intensely hot, will be non-luminous, the want of luminosity being also perhaps in part due to the fact that the larger body of gas ascending from the Bunsen burner, and obtained wholly from inside, may provide a wider road for the passage upwards rather than outwards of any amount of displaced compulsive force which may remain unutilized. That this explanation and not Davy's explanation—according to which the luminosity of an olefiant gas flame was supposed to be due to unconsumed particles of carbon which are

raised to a state of incandescence when in suspension in the flame; and the non-luminosity of the flame when air is mixed with the gas to be due to the fact of all the carbon particles being consumed—is more nearly the correct one seems to be shown by the fact that the flame also becomes non-luminous if instead of air a non-inflammable gas such as nitrogen or carbonic acid is mixed with the olefiant gas, (Roscoe's "Chemistry," vol. i., p. 187), thus reducing the consumption of gas, and providing in the large column of gas ascending from the burner a ready road and a wider area for the upward rather than outward displacement of compulsive force. This conclusion seems further to be strengthened by the act that Professor Frankland found (Roscoe, vol. i., p. 188) that oxygen and hydrogen, which ordinarily burn with a non-luminous flame, give rise to a luminous flame when burning under a pressure of 20 atmospheres. The luminosity of the flame of the gases burning under pressure may perhaps be assumed to be due to the compulsive force in excess of the amount required to induce combination, being displaced by the emission of repulsive force, which accompanies the combination of two gases.

74. We thus see that the science of chemistry reveals plainly the fact that all matter is made up of aggregations of minute bodies, or particles, which have a general tendency to arrange themselves in

groups. We also see that while there is nothing, in the facts revealed by chemistry, inconsistent with the assumption that every one of the particles of which matter is made up is in the grasp of the two opposite forces of compulsion and repulsion—by the one, of which, particles are drawn together into groups, and the groups, or single particles, are drawn together into gaseous, liquid, or solid masses, and these masses into heavenly bodies; whilst by the other the particles are kept apart particle from particle, so that even when they are most closely united together the central atoms of the particles are never in actual contact, and whenever this force preponderates particle is driven away from particle, group from group, and mass from mass, and a general scattering and dissociation takes place—there is, on the contrary, much in the peculiar manner in which particles, when free to move, arrange themselves, as we have seen, almost invariably in groups; also in the fact that, on the one hand, when force is impressed upon a mass of matter, certain definite changes occur in the mass, denoting, if the force is one of attraction, a drawing together in some way of the particles, either of the mass as a whole, or of the groups of which the mass is made up; and if the force is one of heat or repulsion, an expansion or a separation of the particles either of the mass as a whole or in the groups of which the mass is made

up; and on the other hand, when changes occur in a mass of matter an emission of force takes place, either of attraction or compulsion if the change involves the separation of the particles, or of repulsion or heat if the change involves a drawing together of the particles; also in the way in which, as we have seen, combination is brought about by compulsive force if the particles are expanded, or by repulsive force if they are condensed,—to support this view.

75. Probably, however, the most striking proof of the accuracy of this view is to be found in the fact that a piece of platinum is able, on the one hand, as is well known, when it is heated and plunged into a mixed mass of oxygen and hydrogen gas to force the gases to combine and form water; and on the other hand (see Grove's "Correlation of Physical Forces" p. 50), when at a white heat it is plunged into a mass of water so as to be very suddenly cooled, is able to decompose some of the water into a mixed mass of oxygen and hydrogen gas. For here, plainly, we see compulsive force displaced by heat forcing gases to combine; and repulsive force displaced by rapid cooling forcing combined gases to separate.

CHAPTER IV.

ELECTRICITY AND MAGNETISM.

76. From a consideration of the forces to which chemical action is due, we turn naturally to the consideration of those to which electrical action is due, for indeed a little careful consideration will show that chemical action runs into electrical action, or electrical action into chemical action, at every step.

77. If then we take a quantity of water to which a small quantity of sulphuric acid has been added, and place a plate of zinc, of which the surface has been amalgamated with mercury, in the weak solution of water and sulphuric acid at the ordinary temperature of the atmosphere, we shall find that the zinc will remain practically unaffected. If, however, the zinc is continually heated while still immersed in the weak solution of water and sulphuric acid, we shall find that an energetic action will go on between the zinc and the acid, whereby some of the zinc particles will displace the hydrogen particles in some of the groups of particles of which

sulphuric acid is made up, with the result of converting the sulphuric acid groups into sulphate of zinc groups, and of liberating hydrogen in the free state. And we thus see that to enable the action between the zinc and the sulphuric acid to proceed energetically a supply of repulsive force, in the form of heat, is required. But if now, instead of heating the zinc, a piece of stout copper wire is attached to it, and another piece of stout copper wire attached to a plate of copper; and then the plate of copper is immersed in the weak solution of water and sulphuric acid alongside of the zinc, but not touching it, we shall find that, if the copper wire connected with the zinc is made to touch the copper wire connected with the copper plate, energetic action between the zinc and the sulphuric acid will be set up, accompanied with a disengagement of bubbles of hydrogen at the copper plate, though there will practically be no action between the copper and the sulphuric acid; but if the two wires are separated the action between the zinc and the sulphuric acid will cease. Now we have seen that when the zinc plate alone was immersed in the diluted sulphuric acid, in order that energetic action between the zinc and the sulphuric acid might be set up, the zinc must be supplied with repulsive force in the form of heat; and when then we find that if a zinc and a copper plate are immersed together in the diluted sulphuric acid, energetic

action between the zinc and the sulphuric acid goes on whenever the zinc and the copper plates are connected together, and ceases whenever they are separated, we can understand that the function of the copper plate is a double one—namely, to supply repulsive force to the zinc and to receive from the zinc compulsive force; and that, when the zinc and the copper are connected together by a wire, a flow of repulsive force takes place along the wire in one direction, i.e. from the copper to the zinc, and a flow of compulsive force in the other direction, i.e. from the zinc to the copper. That the copper plate receives compulsive force is apparent, because the bubbles of displaced hydrogen collect upon it, being attracted, or wrenched away from the sulphuric acid groups by the compulsive force upon the copper plate; but besides this, if in place of employing a single pair of plates of zinc and copper a number of pairs of plates are made up into a battery, a sensible emission of light will, as we shall see, pass from the wires or poles of the battery if the ends of the wires are first brought together and then separated by a short interval; and on the assumption that light represents compulsive force, we have thus then here ocular demonstration of the fact that compulsive force passes along the wires: also that repulsive force passes along the wire is apparent, because if the ends of the copper wire are connected by a

piece of fine platinum wire instead of being brought directly in contact, the piece of fine platinum wire will be heated owing plainly to its inability to transfer the whole of the repulsive force which it receives at one end to the other end. In addition it may be well to remember Faraday's experiments, by which he showed that when a pair of metal plates in dilute acid are in the relation to each other of positive and negative, or in the same relation as zinc to copper, the effect of heating the negative is largely to increase the action on the positive plate (Faraday's "Experimental Researches in Electricity," vol. ii., p. 63), since they confirm in a remarkable manner the accuracy of this explanation. But we have further evidence than this; for if the ends of the two pieces of copper wire connected respectively with the zinc and copper plates, instead of being directly connected, are dipped both of them in a solution of sulphate of copper, it will be found that the action between the zinc and the sulphuric acid will be set up, though more feebly than when the ends of the two wires are directly connected; but at the same time the end of the wire connected with the copper plate will be corroded away in the sulphate of copper solution; whilst the end of the wire from the zinc will grow, receiving from the sulphate of copper solution a deposit of pure copper (Ferguson's "Electricity,"

p. 109). Here then plainly we have the wire from the copper plate showing the action of repulsive force, which, as we have already seen in paragraph 56, in the form of heat facilitates the solution of solids by liquids; and the wire from the zinc plate showing the action of compulsive force, in attracting to itself the particles of pure copper corroded away from the end of the wire from the copper plate.

78. If, in place of taking a single pair of copper and zinc plates, a large number of pairs are taken, and each pair immersed in diluted sulphuric acid in a separate cell, in such a way that the copper plates all face one way, and the zinc plates all face the other way; and if then a long copper wire is attached to the last copper plate at one end of the series of pairs, and a long copper wire to the last zinc plate at the other end of the series of pairs; and if all the intermediate copper plates are connected by a short wire each to the zinc plate of the pair next to it, a powerful battery is obtained, of which the two long wires attached to the end plates, one to the copper, and the other to the zinc, are the poles, or wires corresponding to the two wires of the single pair. The end of the wire from the zinc plate is called the negative pole, and the end of the wire from the copper plate is called the positive pole ot the battery. The explanation of the increased power

obtained with this arrangement, above that obtained from a single pair of plates of the same area as the combined plates, is possibly this, that action being started by the end plates the particles on one face of each copper plate supply repulsive force to and receive compulsive force from the zinc plates in the same cell as themselves through the liquid, whilst through the wires the particles of the other faces of the copper plates supply repulsive force to and receive compulsive force from the opposite faces of the zinc plates connected with them in adjoining cells, and thus both faces of both plates are utilized. If the poles, or wires connecting the terminal plates of a battery, are of any considerable length, we can understand that the passage of one force along the wire may displace to a considerable extent the opposite force, and thus in either direction a flow of mixed forces will take place; the secondary action arising from the combination of some of the particles of liberated hydrogen with particles of oxygen arising from air in solution in the liquid may also cause more or less a mixture of the forces, the same result may also be brought about by combinations due to impurities in the metallic plates. Hence, though at the positive pole—i.e. the end of the wire connected with the copper plate—the emission of repulsive force for reasons already explained predominates, and at the

negative pole, or the end of the wire connected with the zinc plate, the emission of compulsive force predominates at both poles, the emission is one of mixed force.

79. If the poles of a powerful battery are brought together, so as to touch, and then separated for a short distance, force continues to pass between the poles, and its passage across the space separating the poles will be marked by an emission of light and heat generally known as the electric light. If the poles are furnished with carbon points, the carbon of the positive pole, or wire attached to the copper plate, will waste away and be hollowed out; and a portion of the carbon thus detached from the carbon of the positive pole will be heaped upon the carbon of the negative pole, or wire connected with the zinc plate; and thus the emission at the positive pole will give practical proof of the action of repulsive force, and the emission at the negative pole will give practical proof of the action of compulsive force, in the same way as we have seen the corresponding wires with a single pair of plates manifested, when dipped in a solution of sulphate of copper, respectively emissions of repulsive and compulsive force.

80. If plates of platinum are attached to the two poles of a battery, and the platinum plates are then plunged into a vessel containing slightly acidulated

water, it is found that the water is decomposed into the gases oxygen and hydrogen of which (see paragraph 59) it is made up, the hydrogen particles going off at the negative pole the oxygen particles at the positive pole. We shall be able to understand the reason of this if we remember that when the two poles are dipped into a solution of sulphate of copper the positive pole, if it is of copper wire, is corroded away by the action of the repulsive force which it conveys, owing to the copper particles at the end of the wire being unable to transfer repulsive force to the particles of the liquid as fast as they receive repulsive force from the plate, and therefore moving off under the action of the repulsive force; and remember too that with the electric light the particles of the carbon point at the positive pole when unable to transfer to the particles of the air the whole of the repulsive force which they receive move off and, like the copper particles in the sulphate of copper solution, are heaped upon the negative pole, which by the compulsive force, which it conveys, is able to attract them; also if at the same time we consider that when the wires are furnished with platinum plates, the wires by the large amount of conducting surface the plates afford are brought in contact with a very large number of liquid particles, and are consequently able to transfer force to the liquid as fast as they receive it: for we shall then see how it

may be possible for the liquid groups of particles at the positive pole now in their turn to be given a greater amount of repulsive force than they can transfer to other liquid groups of particles contiguous to them; and how if then the groups of particles are clogged in their movements by the acid particles with which they are associated (for perfectly pure water is not readily decomposed by an electric current) the effect may be that the groups will break up and that the lighter and more condensible hydrogen particles will move across and transfer force by impact to the negative pole in the way described in paragraph 49, just as the particles of copper do when the poles are dipped in a solution of sulphate of copper, whilst the heavier oxygen particles will be set free at once at the positive pole. We have proof in Faraday's discovery that, if an electric current is transmitted through a series of different electrolytes, each electrolyte will be decomposed exactly as it would be if it were the only electrolyte through which the current passed (Lardner's "Natural Philosophy," p. 239), that this is the correct explanation of the electrolysis, or decomposition of water or other electrolytes by the electric current; for, to quote from Miller's "Chemistry," vol. i., p. 575, "It has been amply proved by experiment that for every 65 milligrammes of zinc which is dissolved in any one cell of the battery, provided

local action be prevented, 18 milligrammes of water are decomposed in the voltameter, or if . . . several electrolytes be arranged in succession each compound will experience a decomposition proportional to its chemical equivalent. For instance—if the current be made to pass first through fused plumbic iodide (PbI_2) and then through fused stannous chloride, $SnCl_2$—for each 65 milligrammes of zinc dissolved in any one cell of the battery 207 milligrammes of lead and 118 milligrammes of tin will be separated on the respective platinodes, whilst 254 (or 2 × 127) milligrammes of iodine and 71 (or 2 × 35.5) milligrammes of chlorine will be evolved at the respective zincodes. These numbers correspond with the chemical equivalents (not the atomic weights) of the several elements named." And since it thus appears that the weights of the several elementary substances displaced from the electrolytes are exactly in the same proportion as the weights in which the substances combine in forming the several electrolytes, it is clear that, for every particle of zinc consumed in the cell, one group of particles is decomposed or broken up in every one of the electrolytes through which the electric current passes. And since also (as we have seen at paragraph 77) the repulsive force by which the particles of the zinc plate in one of the cells of a battery are enabled to displace the hydrogen particles from the groups

of particles of which the sulphuric acid, in the solution in which the plates are immersed, is made up, is supplied by the copper plate, and passes along the wires or poles of the battery to the zinc plate, it is easy to see that if, instead of finding an uninterrupted road all the way through the wires of the battery, the repulsive force in its passage from the copper to the zinc plate finds its road broken up by the intrusion of several electrolytes in each of which the groups consist, as in the case of water, plumbic iodide, and stannous chloride, of the same number, namely three, of particles, and therefore are similar to one another, and in all of which the resistance is so great that a passage can only be effected by breaking up the groups of particles in the way described in the case of acidulated water; and if as is clearly the case the absolute quantity of force required to effect the combustion of a single zinc particle in the zinc plate and to break up a group of particles in any one of the electrolytes is constant, then before sufficient force to effect the combustion of a single zinc particle reaches the zinc plate the same number of groups of particles must be broken up in each of the electrolytes, whether the number broken up is great or few; for since the groups in each case are similar, and we may therefore suppose the transfer of repulsive force in each case to be effected through the same number

of groups; and since the transfer through an electrolyte is effected, as we have seen, by breaking up groups of particles: hence although in the first electrolyte or the one nearest to the copper plate the absolute quantity of force transferred will be greater than in the second or third or fourth electrolytes, and in the second greater than in the third or fourth, and so on, the transfer will involve the breaking up of the same number of groups of particles in each electrolyte. The decomposition of the electrolytes is thus seen to be effected concurrently with the combustion of zinc in the battery cell, and is therefore not consequent upon or brought about by force developed by the consumption of the zinc; for if this were the case the consumption of zinc would be greater with an increase in the number of electrolytes to be decomposed, since a greater amount of work would then have to be done, whereas we know that the consumption of zinc is just the same whether the number of electrolytes decomposed be many or few, and the rate only at which the zinc is consumed is reduced by an increase in the number of the electrolytes.

The zinc plate possibly may obtain repulsive force from the mass of the electrolyte nearest to it in addition to the supply coming from the copper plate, and the electrolyte nearest to the zinc plate in its turn may obtain repulsive force from the mass

of the electrolyte next to it; and so on: and in this way perhaps the regularity of the flow of force may be assisted. If in place of passing the current through a substance such as acidulated water the current is passed through some substance which requires a greater supply of force to effect the breaking up of its groups than the amount required to effect the displacement, of a hydrogen, by a zinc particle, in the sulphuric acid groups, no decomposition of the substance will take place, for the groups of particles of such a substance will be able to transfer the repulsive force, which reaches them, from one to another, and so across from the positive to the negative pole, as fast as they receive it.

81. We are thus able to trace almost with certainty an inflow of repulsive force by which the consumption of zinc in the battery is effected, from the copper to the zinc plate. We can also almost with certainty show, from the effect of the electric spark in supplying to particles of mixed gases, such s oxygen and hydrogen or chlorine and hydrogen, rough which it is passed sufficient compulsive ce to effect the combination of the gases, that outflow of compulsive force, due to the displacement of compulsive force, which must occur before hard zinc is converted into the soft sulphate of c, really takes place from the zinc plate. The ction of the electric spark, in thus bringing about

the combination of a mixture of two gases through which it passes, has before been alluded to; we may assume, however, that the gaseous particles about the negative pole or the end of the wire from the zinc plate are drawn towards the negative pole, under the action of a greater amount of compulsive force than they are able to transfer, so forcibly that they are sufficiently condensed to bring about combination. The action of the electric spark when passed through oxygen in effecting the condensation of the oxygen into ozone, already alluded to in paragraph 66, should not be lost sight of. The fact also that though the electric spark can bring about combination, in a light mixture, such as one of oxygen and hydrogen, or even one of oxygen and nitrogen, it cannot effect combination in a dense mixture such as one of chlorine and oxygen, is noteworthy.

82. We have thus endeavoured to show the force, origin, and action of the electric current in a Galvanic Battery, which may, it should be remembered, be made up with any two substances, provided that the liquid in the cells acts more energetically upon one of the substances than upon the other. There can hardly be a doubt as to the currents of Frictional Electricity, to which we may now turn our attention, having a force origin; for with frictional electricity force is, as it were, put into the frictional

electric machine, and therefore clearly force can be got out.

83. If now a tube of glass, or a stick of sealing-wax—or some other substance which like glass, or sealing-wax, but unlike metallic substances, does not allow of the free passage of electric currents over its surface, and is therefore called a non-conductor—is rubbed several times in the same direction with a dry silk rubber, and then the rubber smartly removed, it is found that the rubbed portion of the glass, or sealing-wax, is endued with the power of attracting to it light substances, such as small pieces of paper, thread, &c. If the rubber is insulated, i.e. attached to some non-conducting substance, which will not allow an electric current from the rubber to pass over its surface, it will be found that the rubber also possesses the same power of attracting light substances.

If the glass tube, after it has been rubbed, is brought near to a pith ball suspended so as to swing freely from an insulating stand, the pith ball will first be briskly attracted to the glass tube; but after touching the glass tube and remaining in contact with it for a moment, the pith ball will be just as briskly repelled. If the glass tube is a second time brought near the pith ball it will repel, instead of attracting, the pith ball. If the insulated rubber is now brought near the pith ball, it will

attract the pith ball; and then after contact repel it, just as the glass tube did at first. If the glass tube is then once more brought near the pith ball it will now attract it, although the rubber continues to repel the pith ball. If a stick of sealing-wax after being rubbed by a piece of dry flannel is brought near to the pith ball, which is thus attracted by the glass tube and repelled by the rubber, the stick of sealing-wax will repel the pith ball, just as the rubber of the glass tube does; but the flannel rubber of the sealing-wax, if insulated, will attract the pith ball, just as the glass tube does. Hence we see that the pith ball, when charged with the same electricity as that developed in the rubber of the glass tube, is attracted by the glass tube and by the rubber of the sealing-wax, but is repelled by the rubber of the glass tube and by the sealing-wax; also that the pith-ball, when charged with the same electricity as that developed in the glass tube, is attracted by the rubber of the glass tube and by the sealing-wax, and repelled by the glass tube and by the rubber of the sealing-wax.

To understand the nature of the power of attracting and repelling an insulated pith ball developed, in the glass and sealing-wax and in their respective insulated rubbers, by the action of rubbing, we must remember that when a body is compressed by force applied at both ends, or applied at one end and

resisted or reflected at the other, repulsive force is displaced laterally in the manner indicated in paragraph 42; and at the same time its particles lose a portion of the repulsive force in their force sheaths, and gain a corresponding portion of compulsive force. As soon, however, as the forces causing compression are taken off, the displaced repulsive force, if the body is elastic, at once returns to its proper position, and restores the body to its ordinary shape; but the lost repulsive force has still to be got back and the excess of compulsive force got rid of before the body returns to its normal state. If the body is a good conductor, as metals are, the excess of compulsive force passes off at once; but if the body is a bad conductor, as glass or sealing-wax is, the excess of compulsive force is transferre slowly to the particles of the air, or of contiguo substances. But when a body is thus compress by force applied at both ends the compulsive fo which it receives at one end, is acting towar different centre from that which it receives other end.

Now the silk rubber and the glass tube, flannel rubber and the stick of sealing-wa the position of a body compressed by forc at both ends, and thus receiving a suppl pulsive force; but the rubber receives force acting towards a different centre, ar

differing directionally from the compulsive force which the glass tube or the stick of sealing-wax receives. But besides receiving by pressure compulsive force, the glass or the sealing-wax and the rubber receive by motion and friction, in the manner explained in paragraph 47, either compulsive or repulsive force, according as the friction is grinding or tearing friction. There is therefore a plain reason why the force imparted by a rubber to a soft substance, such as sealing-wax, should be different from the force imparted to a hard substance such as glass is. And we have seen already, in paragraph 50, from the case of a projectile moving in a parabolic path under the simultaneous action of repulsive force derived from the explosion of a charge of gunpowder in a gun and of the compulsive force of gravity, that a body can be acted upon independently by the two forces of compulsion and repulsion at the same time, provided that the two forces are not acting about the same centre. We may therefore assume that the act of rubbing communicates to the glass and to the rubber of the sealing-wax compulsive force in two directions, namely, one part, due to pressure, in a direction perpendicular to the rubbed surface; the other part due to friction, in a direction parallel to the rubbed surface: also that the same action communicates to the rubber of the glass and to the sealing-wax directional compulsive

force acting in a direction perpendicular to the rubbed surface, and directional repulsive force acting in a direction parallel to the rubbed surface. Hence when the rubbing action ceases the glass and the rubber of the sealing-wax are in the position of the zinc plate in one of the cells of a galvanic battery, since they like the zinc plate both have an excess of compulsive and a deficiency of repulsive force; also the rubber of the glass tube and the sealing-wax are in respect of the force received by friction in the position of the copper plate in one of the cells of a galvanic battery, since like the copper plate they give up repulsive and receive compulsive force.

So long as the rubber and the body rubbed remain in contact they will continue gradually each at their respective outer surfaces to dissipate their excess of compulsive force and to make good their deficiency of repulsive force, just as they would do if both were parts of one solid body, and so no marked action at the surface of either will be perceptible; but if at any time the rubber and the rubbed body are forcibly separated, and their inner surfaces at which all the rubbing action between them has taken effect are exposed, then a marked action at the exposed surfaces will become perceptible.

84. We have seen in paragraph 24 that surface particles of solids both hold on to and transfer force to

and receive force from the particles of gases contiguous to them; hence there will be little difficulty in understanding how the surface particles of bodies to which an excess of compulsive or of repulsive force has been communicated by the act of rubbing, can gradually transfer that excess of force to the particles of air contiguous to them, and can take from the particles of air a corresponding amount of the opposite force displaced by the transfer—the transfer of force to air particles would go on more slowly than would a similar transfer to solid particles, but it will go on regularly nevertheless. So also we can understand how air particles having received an excess of force from the surface particles of one solid may transfer a portion of such excess of force to the surface particles af another solid with which they may come in contact, and may receive from such solid in exchange a corresponding amount of the opposite force displaced by the transfer. This, which is Faraday's view ("Experimental Researches in Electricity," vol. i., p. 362), is plainly in strict accordance with all that we have hitherto learnt in regard to the transfer of force.

85. From the fact that both the rubber and the rubbed body receive compulsive force during the process of rubbing we can understand the way in which both the rubbed body and the rubber are able to attract light bodies.

86. We have seen that the glass tube after it had been rubbed was able to attract an insulated pith ball, but that after the pith ball had touched the glass tube it was then repelled instead of being attracted by the glass tube. The probable explanation of this is that a portion of the excess of force about the surface particles of the tube is transferred directly to the particles of the pith ball, and a corresponding amount of the opposite force transferred by the pith ball to the tube as soon as the pith ball comes in contact with the glass tube; this interchange of force goes on between the ball and the tube with very great rapidity until the particles of the ball have the same excess of compulsive force about them that those of the glass tube have. Then whereas before contact the surface particles of the glass tube alone transferred force to the air particles, after contact the particles both of the tube and of the ball transfer compulsive force to the particles of air about them, and in this way both the tube and the ball gather about their surfaces layers of condensed air particles, which act like solid envelopes in keeping the ball and the tube apart. We have seen in paragraph 24 that, when a solid is plunged into a liquid, it is frequently found that portions of the surface of the solid have condensed thick films of air particles upon them, and that these films completely prevent the liquid particles from coming

in contact with the particles of the solid, though in the air the film is quite invisible: and in the same way it is clearly possible for the glass tube and the pith ball to condense layers of air particles upon their surfaces; only the layers about the ball and tube will be as much thicker than the film which protects the surface of a solid plunged into the water, as the force developed upon the surface of the tube, or ball, is in excess of the amount of force by which ordinarily the surface particles of solids hold on to the particles of air contiguous to them. The layer of condensed air particles about an electrified body will protect the body from contact with any other body electrified in the same way and having a similar layer of condensed air particles about its surface; but the layer of condensed air particles will not keep off from the electrified body an unelectrified body, which having more particles in its composition than a similar volume of air has, is able to receive from the electrified body a proportionately greater quantity of compulsive force than a similar volume of air can, and is therefore attracted to the electrified body; with the result of displacing a portion of the layer of condensed air particles about the body; and still less will the layer of condensed air particles keep off an electrified body with an excess of the opposite electricity, or repulsive force, such as a stick of sealing-wax after

it has been rubbed has, which, as we have seen, has an excess of directional repulsive force impressed upon it by the act of rubbing, for the excess of repulsive force upon the stick of sealing-wax will tend to thrust aside the particles forming the layer.

The apparent repulsive effect which two pith balls or two pieces of gold-leaf exercise upon each other when both are charged with the same electricity, may be explained in the same way by the formation of layers of condensed air particles upon the surfaces of both the pith balls or of both of the pieces of gold-leaf.

87. A frictional electric machine is simply a glass tube and rubber on a large scale, though sometimes a glass plate is substituted for the glass tube. In the electric machine both the glass tube and the rubber are provided with wires, and suitable connexions, for conducting away the electricity, or force developed upon both, by the action of rubbing. The wire from the rubber is connected with the earth; and if then, while the machine is working, a second wire connected with the earth is brought close to the wire connected with the glass, sparks of light of much greater length than the sparks obtained with galvanic batteries will pass between the wires. If the ends of the wires are connected by a piece of thin platinum wire the platinum wire is heated in the same way as it is heated, as

we have already seen in paragraph 77, when placed between the poles of a galvanic battery in action.

88. Hence, as pointed out by Faraday, a current of frictional electricity does not differ materially from a current of electricity from a galvanic battery: and we may say generally that in both the current consists of a passage of compulsive force in one direction and a passage of repulsive force in the other direction, though in neither direction is the force absolutely pure and unmixed. We have seen, in the action upon an insulated pith ball of a glass tube or a stick of sealing-wax, after they have been rubbed, a decided manifestation of compulsive force with frictional electricity. We may see an equally decided manifestation of compulsive force with the electricity from a galvanic battery, if one of the wires of the battery is passed round the two arms of a piece of soft iron bent in the form of a horse-shoe, so as to allow the current as it were to spread over a wider surface: for the effect will be to convert the soft iron into an electro-magnet, and to confer upon it the power of attracting masses of iron similar to the power possessed by a piece of loadstone or a common magnet.

89. We may now therefore turn our attention to the study of Magnetism. We find then that a substance called loadstone is sometimes found, which has naturally the power of attracting iron. From

Dana's "Mineralogy" it appears that loadstone is a mixture of two oxides of iron; and it does not therefore appear improbable that the source of power lies in a displacement of compulsive force due to some alteration in the grouping of the particles induced when a mass of some substance, such as iron, which is able to supply the necessary amount of repulsive force to effect the change, is brought near to the mass of loadstone. However that may be, we find that if a bar of steel or hard iron is rubbed several times, always in the same direction, with a piece of loadstone, the bar becomes a magnet, and has then conferred upon it the same power of attracting at both of its ends pieces of iron, which the loadstone has. We find also that, if the same bar of steel, instead of being rubbed with a magnet, is placed in a vertical position and struck several blows with a hammer, it will acquire the same magnetic properties as it acquires when rubbed with a loadstone. We find further that soft iron, though it can be rendered temporarily magnetic by the passage of a current of electricity round it, cannot be rendered permanently magnetic, either by an electric current, or by contact with a loadstone, or by blows with a hammer, in the same way that a bar of steel is rendered magnetic; and if we remember that soft iron is pure iron, and hard iron impure, the fact that soft iron cannot be rendered

permanently magnetic becomes of importance in giving us an insight into the origin of magnetic force. Dr. Lloyd, in his "Treatise on Magnetism," p. 21, has drawn attention to this, and has pointed out that the coercitive power of the magnet is due to the presence, in small quantities, of carbon, phosphorus, arsenic, sulphur, or some other foreign element, and that if these impurities are present in large quantities a bar of iron will resist altogether the development of magnetism in it. Now it is clear that a particle of iron and a particle of carbon in the presence of the moisture of the atmosphere are nearly in the same position as a plate of zinc and a plate of copper in the cell of a battery are, and still more nearly in the position of one of the pairs of a dry pile, which is made up simply of discs of paper coated on one side with silver foil and on the other with zinc foil and piled one upon another, in such a way that the silvered sides all look one way ; and we shall not perhaps find it difficult to understand how the effect of striking with a load-stone or magnet, several times in one direction, a bar containing a number of such pairs of particles disposed irregularly, with the carbon particles in some cases looking one way and in some another way, may be to arrange the pairs of particles in such a way that all the carbon particles will look in one direction, or in the same way that the pairs in

a battery or dry pile are arranged; and that the effect may also be to press the carbon against the iron particles and to set up action between them, and thus in fact to convert the bar into a dry pile composed of many millions of pairs. And we can also see without difficulty, that the effect of striking a similar bar, when in a vertical position, several times with a hammer, must also be to dispose the pairs with the carbon particles all looking in one direction, and to press the carbon against the iron particles. We can further understand that a bar with many millions of pairs of carbon and iron particles disposed in it in the same way as the pairs of plates in a battery would, although, when the pairs of particles were irregularly disposed, it manifested no compulsive action, develop in the presence of the large surface of iron furnished by the bar, the same compulsive force which a wire from a galvanic battery develops, when it is passed round an iron bar. The difficulty is to understand how such a bar can continue permanently to develop by galvanic action sufficient compulsive force to produce the marked attractive action, which a magnet exhibits; since at the rate at which zinc is consumed in a galvanic battery, the iron bar must very soon be corroded away. And if indeed the action of the magnet is as continuous as at first sight it seems to be, this difficulty would be insuperable. But are

we quite sure that the magnet is continuously developing force of the same intensity as that which acts when a piece of iron is brought near the magnet? and may it not be that the approach of the iron sets up an increased action in the magnet? We know that Faraday found that, though there was very little action when a pair of silver and copper plates were immersed in dilute sulphuric acid at the ordinary temperature, and very little action when the copper plate was heated, there was very energetic action when the negative or silver plate alone was heated. And may it not then be that the pairs of carbon and iron particles in a magnet are in much the same position as a pair of silver and copper plates in dilute sulphuric acid; in so far that like the silver and copper plates they may require to have a certain amount of repulsive force communicated to the negative or carbon particle before energetic action upon the iron particle is set up? If the distribution of compulsive and repulsive force in the force sheaths of iron particles is such that when paramagnetic substances, such as iron, nickel, cobalt, &c., approach a magnetized bar, repulsive force is transferred to the carbon particles in the pairs of particles in the bar; whilst when diamagnetic substances, such as bismuth, antimony, &c., approach the magnet, repulsive force reaches the iron and not the carbon particles of the pairs of

particles in the magnet, it will be clear that the approach of a mass of iron to the magnet will set up galvanic action in the magnet, and that this action will increase in energy as the mass of iron gets nearer to the magnet, until finally the mass of iron touches the magnet and gives up the whole of the repulsive force it is capable of supplying. Provided that after the mass of iron has joined the magnet the compulsive force, by which the mass of iron was drawn to the magnet, is not displaced from about the surface particles of the mass of iron and the magnet at the point of contact of the two surfaces, the mass of iron will continue to adhere to the magnet after it has reached it without necessitating any further development of compulsive force in the magnet. Hence a keeper may continue to adhere to a horse-shoe magnet, without causing any consumption of material in the magnet beyond that which always goes on from oxidation when any mass of iron is exposed to the atmosphere.

90. With this explanation of the nature and action of a magnet it is quite evident that if a magnet is broken up into any number of pieces each piece will act in the same way as the entire magnet acted; and this is found in practice to be the case. It will also be plain that if two magnets are brought together in such a way that the north pole of one is next the south pole of the one in

front of it all the carbon particles in all the pairs of particles in both magnets will face in the same direction; and thus that the two magnets when thus situated will form parts of one large magnet including the two; accordingly it is found that when two magnets are so situated they attract each other, and joining together have a common north and a common south pole.

91. Since magnets develop compulsive force, it is clear that they may condense about their poles layers of air particles, similar to the layers of condensed air particles, which apparently form, as shown in paragraph 86, about the surfaces of rubbed glass tubes or sticks of sealing-wax. And we have evidence that magnets do so condense air particles about their poles (Ferguson's "Electricity," p. 205) in the fact that if a disc or cube of copper is made to rotate between the poles of a powerful electro-magnet the disc encounters greater resistance when the magnet is made than it does when the magnet is unmade. Such layers of condensed particles would prevent the north poles of two magnets, if they were brought together, from coming in contact; and in this way the apparent repulsive action noticed between the north poles of two magnets when they are brought together may perhaps be explained: though at the same time it is of course possible that the repulsive action may be really due to repulsive force.

The action of a current flowing along a wire in exercising sometimes a repulsive action upon a magnet brought near to the wire, can be explained on the assumption that the passage of the current causes a condensed layer of air particles to collect about the wire similar to the layers which form about pith balls or pieces of gold leaf when electrified, and that this layer of particles interferes with a similar layer formed about the magnet. We know that a copper wire through which a current is passing attracts iron filings in the same way that a magnet does; and therefore there is a plain reason why such a layer of condensed air particles as that indicated, should form about the wire; there is also a plain reason why, when the circumstances are such that the layer of condensed air particles about the wire does not interfere with the layer of condensed particles about the magnet, the wire should attract the magnet just as it attracts iron filings. We know from Dr. Faraday's researches that a mass of matter placed between the poles of an electro-magnet, in such a way as to be free to swing, will place itself either axially, i.e. with its longer axis in the line joining the poles, or equatorially, i.e. with its longer axis across or at right angles to the line joining the poles; and we also know that a substance, which when in one medium places itself axially, will in some cases, when in a

different medium, place itself equatorially (Gordon's "Physical Treatise on Electricity and Magnetism," vol. ii., p. 30). Hence it becomes apparent that the mass of matter places itself axially, when its particles are able to transfer the force developed about the poles of the magnet better than the particles of the air or other mediums in which the magnet and the mass of matter are able to transfer force, and equatorially when its particles do not transfer the force developed about the poles of the magnet so well as do the particles of the medium; and when consequently the mass of matter would, if it placed itself axially, interfere with the formation of condensed layers of particles of the medium about the poles of the magnet in a manner which it does not do if it is placed equatorially. We can therefore understand that the fact of a magnet when free to swing placing itself axially with reference to currents of force developed upon the earth's surface, though it implies that the magnet is sensitive to the action of these force currents, no more implies any development of force within the magnet than does the fact of any other mass of matter placing itself axially between the poles of a magnet imply a development of force within that mass.

92. The fact that heat weakens the action of a magnet and finally destroys all magnetic power can be explained on the assumption that the first effect

of the application of heat to the magnet is to drive off the moisture upon which the action of the magnet depends; just as, by driving off the moisture upon which the action of a dry pile depends, the application of heat to a dry pile such as Deluc's is found to destroy the action of the pile (Miller's "Chemistry," part i., p. 607). The secondary effect of the application of heat to a magnet may, when the heat is very great, be assumed to be to cause, by setting up a considerable amount of movement in the particles of the bar, a disarrangement of the pairs of particles on the correct arrangement of which the action of the bar as a magnet depends. When the pairs of particles have been disarranged in such a way that all the carbon particles no longer face one way, but some face in one way and some in another, the action of one pair will interfere with the action of another, just as is the case in a bar before it is magnetized, and the bar will be found to have lost all its magnetism.

93. We have seen that when a mass of iron is brought near to one of the poles of a magnet repulsive force passes from the iron to the magnet and compulsive force from the magnet to the iron. If the iron mass is in the form of a coil of insulated wire, a momentary current of compulsive force, going from the end nearest the magnet to the distant end of the coil, and of repulsive force, passing from the

distant end of the coil to the end nearest to the magnet, will be set up in the coil; when the coil is removed from the magnet a similar current, but in the opposite direction, will pass along the wire, as the balance of forces no longer disturbed by the proximity of the magnet is restored. If the two ends of such a coil are connected by a wire, a current of force, consisting of compulsive force going in one direction and of repulsive force going in the opposite direction, will pass along the wire each time the coil is brought near to and taken away from one of the poles of a magnet. If some arrangement is adopted whereby the coil is for a number of times in rapid succession presented to and removed from one of the poles of a magnet, and if then the currents set up in the coil in one direction only are taken, a current, intermittent indeed, but, in other respects, similar to the current obtained with a galvanic battery, or a frictional electric machine, will thus be obtained from the magnet.

94. We have already alluded to the action of force currents about the earth in causing a magnet, when able to swing freely, to take up always a particular position; and we may therefore now turn to the consideration of the phenomena connected with thermo-electricity, to which probably these force currents are due.

We find then (Roscoe's "Chemistry," vol. ii., part i.,

p. 17) that the quantity of heat required to raise the temperature of a given weight of iron through 1° is nearly four times as great as the quantity required to raise the temperature of the same weight of platinum through 1°. And since when two bodies are brought into contact, the fact of one of them appearing to be hot shows that the hot body is transferring repulsive force to the other; and the fact of one of the bodies, under the same circumstances, appearing cold shows that the cold body is taking repulsive force from the other; and since a high temperature in a mass of matter indicates that a large amount of repulsive force is stored about the particles of the mass; and since repulsive force cannot be stored without the displacement to a corresponding amount of compulsive force, and the high temperature therefore indicates also that the body, though it has gained a large amount of repulsive force, has lost a correspondingly large amount of compulsive force, from its particles: we may assume that the fact that when two bodies are heated to the same extent and in the same way one is raised to a much higher temperature than the other indicates that particles of the one part more readily with compulsive force than do those of the other, and also that the one at the lower temperature has transferred to the particles of surrounding substances a larger proportion of the repulsive force in

the form of heat it has received than the other has done, whilst the one at the higher temperature has transferred a much larger proportion of compulsive force than the other has done.

And when then we find that a given weight of iron takes nearly four times as much heat to raise its temperature through 1° that the same weight of platinum takes, we may conclude that for a rise of 1° of temperature the particles of iron transfer about four times as much heat to the particles of surrounding substances as those of platinum do; but that, on the other hand, the particles of platinum will transfer nearly four times as much displaced compulsive force to the particles of surrounding substances as the iron particles do.

If then we take a bar of platinum and a bar of iron, and after uniting the bars together at one end and connecting the other ends of the bars together by a wire, proceed to heat the two bars at the point where they are joined together, we may expect, from what we have already learnt in regard to the difference of effect produced by heat upon a bar of platinum and a bar of iron, that compulsive force will pass along the wire from the platinum to the iron and repulsive force from the iron to the platinum, and that we shall get a current of electricity similar to the currents obtained with galvanic batteries and frictional electrical machines. Accordingly we find

that this is the case, and that a galvanometer placed in the circuit will indicate the passage of a current, just as it does when placed in the circuit of a galvanic battery or frictional electric machine. The current, however, in the case of a thermo-electric pair is very much feebler than that obtained from a galvanic pair.

If we take two bars of any other metals which have a different capacity for retaining heat, and make the two up into a pair in the same way as the bars of platinum and iron were made up, we shall be able to obtain similar currents of electricity. And we can take several of these pairs and connect them together in the same order as the pairs of a galvanic battery are connected together and thus make up a thermo-electric battery.

95. The surface of the earth, broken up as it is with masses of land and water, which differ from each other in their capacity for retaining heat, resembles a huge thermo-electric battery, in which the atmosphere takes the place of the wires, and in which the junctions of the pairs of which the battery is made up are heated at the one end or pole, whether north or south of the earth, which for the time is turned to the sun, and cooled at the other which for the time is turned away from the sun, by the collection of ice or snow which takes place.

96. We have thus seen that currents of electricity,

consisting of force of one kind passing in from one direction and of force of the opposite kind passing out in the opposite direction, are obtained from chemical force with a galvanic battery or with a magnet, from physical force with a frictional electric machine, and from heat in a thermo-electric battery, and thus to make the chain complete we have only to show that currents of electricity can be obtained from Light. And this has been done by Professor W. G. Adams and Mr. Day, who have shown (Gordon's "Electricity and Magnetism," vol. ii., p. 266), with light from different sources, that if platinum wires are attached to the two ends of a piece of selenium and the free ends of the wires are brought together, a current of electricity passes when one portion of the piece of selenium is illuminated. The direction of the current, when the junction of the platinum wire and the selenium is illuminated, is said to be from the selenium to the platinum, and we may hence perhaps conclude that the current represents displaced repulsive force passing from the selenium to the platinum, and displaced compulsive force passing from the platinum to the selenium. We are thus able to demonstrate completely the correspondence which subsists electrically between all forms of force known to us, and to show that electricity represents essentially a transference of force.

97. The action of condensers such as the Leyden jar and its modifications, in enabling a number of small charges to be stored up until a large charge has been accumulated, is perfectly intelligible.

98. The action also of induction coils can easily be understood; for we have seen that with the galvanic battery repulsive force passes from the copper plate and from contiguous substances along the wire to the zinc plate, and that compulsive force passes along the same wire from the zinc plate to the copper plate and to contiguous substances; and if such a wire is made in the form of a coil in which a large amount of surface is exposed to the air, it will clearly take a considerable amount of repulsive force from, and transfer a corresponding amount of compulsive force to, the particles of air in contact with it; if further, another coil of insulated wire is slipped over the first coil in such a way as not to be anywhere in contact with the first coil, it is plain that the second coil will take the place of some of the particles of air from which the first coil before took repulsive force, and to which it transferred compulsive force, and that then the second coil, through the particles of air intervening between it and the first coil, will transfer repulsive force to, and receive compulsive force from, the first coil, just as, though more actively than, the particles of air which it replaced did; it is also plain that just as the two

forces pass through the first coil in opposite directions, so also will they pass in opposite directions through the second coil; and if therefore the two ends of the second coil are connected by two wires, a momentary current will pass through these wires, until a state of force equilibrium in the first and second coils is arrived at, in which state repulsive force will be at a maximum at one end of the second coil, and compulsive force at a maximnm at the other; so that if the second coil is suddenly removed from the neighbourhood of the first, and the force equilibrium thus again disturbed, another momentary current will pass through the wires connecting the two ends of the second coil, in the opposite direction to that in which the first current passed. Hence each time the second coil is slipped on to and slipped off the first coil, currents in opposite directions will circulate through the second coil; and if the second coil is rapidly slipped on and off the first coil for a number of times in succession, a succession of currents in opposite directions will traverse the wires connecting the two ends of the second coil. It is clear also that the same effect will be attained if, in place of slipping the second coil on and off the first coil, the connexion between the first coil and the battery is rapidly made and broken for a number of times in succession, so that a current from the battery will momentarily circulate and then cease to circulate

through the first coil. We may assume that the second coil will act as an accumulator, so that the longer it is the greater will be the amount of force stored up in it, and the greater consequently the intensity of the currents it is able to set up.

If we take an additional wire, and connect its ends with the wires of the coil when currents in one direction are passing and disconnect the ends when currents in the opposite direction are passing, we can obtain currents all in one direction from the second coil.

If we separate the wires connecting the two ends of the second coil by a short interval, the effect will be as it were to dam up or accumulate force of opposite kinds in the two wires, just as force of opposite kinds is accumulated in a Leyden jar, until the compulsive force in one of the wires has so far condensed the air particles between the wires—much he same way, as we have seen at paragraph 91, air particles are condensed about the poles of a t—as to provide a road by which the two forces s. Thus with an arrangement of this sort, s called an induction coil, and which some- as in the case of Dr. Spottiswoode's great coil, ried out on a very large scale, sparks can be ined many times longer than those which a ery without such an arrangement is able to ish.

99. We thus see that, on the one hand, with a galvanic battery or with a frictional electric machine we may obtain from force of any kind, whether chemical or physical, currents of electricity, from which—if we confine them to a narrow road, by making them at some point pass through a short length of fine wire, or for a short distance pass across a break filled with air or other gaseous particles, with which, owing to the smallness of the number of particles in a given volume in comparison with the number of particles in the same volume of a solid, the road is practically narrowed just as much as with a fine wire—we shall obtain a development of light or of heat, or of both (and it is noticeable that the finer the wire, or the more attenuated the gas through which the current passes, the greater is the development of light and of heat with any current); or if by interposing an electro-magnet in its path we furnish as it were at some point the current with a broad road, as explained in paragraph 88, we shall obtain from the current a development of force.

On the other hand we can, as we have seen, by a thermo-electric battery, or with a piece of selenium with its ends connected by a platinum wire, obtain from light and heat currents of electricity from which, although they are very weak in comparison with currents obtained in other ways, we may, by

furnishing them with a broad path by means of the electro-magnet, obtain a development of compulsive force, or by the Leyden jar as Dr. Quncke has shown (Phil. Magazine, July, 1880, p. 30) we may obtain a development of expansive or repulsive force.

We can therefore, by taking advantage of the fact that when force of one kind enters force of the opposite kind is displaced, and utilizing either the incoming force or the outgoing displaced force according as force of the one kind or of the other is required, convert at pleasure force of any description into light or heat, or light or heat into force of either kind, and can thus show with almost absolute certainty the connexion between light and heat and force of the two kinds.

100. Since heat is most plainly identified with expansive or repulsive force, we might, therefore, even were no other evidence to the fact forthcoming, from a consideration of electrical phenomena alone with reasonable certainty identify light with compulsive force. But there is, as we have already seen, in chemistry, and as we shall see hereafter in physiology and astronomy, and in the consideration of the physical properties of light and heat, a large amount of additional evidence to the same effect forthcoming. And if then any one should ask what is the nature of the Electric Light, we may reply with confidence that it is a development of precisely

the same force as that by which a man draws back an arm or a leg, or as that by which an apple is drawn to the earth when it is detached from the tree, or as that by which the earth and the other planets are continually drawn towards the sun and which is recognized by us as sunlight, or as that by which the flame of a candle or that of a fire draws air to itself. The particular development of force by which the Electric Light is produced is the electric current which, as we have seen, can be obtained in great strength either with a galvanic battery or a frictional electric machine, or from a magnet or electro-magnet, in the way explained in paragraph 93, by utilizing force of any kind to drive, for a number of times in rapid succession, a number of coils usually mounted upon a rotating cylinder, alternately near to and away from the magnet; and thus combining, as it were, a current of the galvanic type from the magnet with a current of the frictional electric type from the force. Emissions of light are obtained when currents set up in any of the above ways are confined to narrow roads. But with the magneto-electric current, in a measure, the steadiness of the galvanic is combined with the intensity of the frictional current; and this therefore is the form generally used for the Electric Light. By using several sets of electro-magnets, and passing the current obtained from one set into a larger set

and so on, a current of great strength can be obtained.

If it should be objected that light cannot be the same as the compulsive force developed on a magnet or by friction on a glass tube or on a piece of sealing-wax, because some substances, such as glass, quartz, &c., are non-conductors of electrical force and yet allow rays of light to pass freely through them, we may point out that Faraday has shown that a body can be charged inductively with electric force more rapidly when a piece of glass is placed between it and the excited body from which the charge is received than it can if the glass is removed, though the body cannot be charged inductively if an uninsulated plate of metal is substituted for the piece of glass; and that the natural inference from this is, that the piece of glass allows the rays of electric force thus impinging perpendicularly on its surface to pass freely through it just as it allows rays of light to pass freely through it. This accords also with the fact that glass allows rays of magnetic force which impinge perpendicularly upon its surface to pass freely through. Glass is indeed a non-conductor of electrical currents which travel in a direction parallel to its surface, but also it reflects and refuses passage to rays of light which are nearly parallel to its surface. Hence glass treats light and electric force very much in the same way.

CHAPTER V.

PHYSICAL PROPERTIES OF LIGHT AND HEAT.

101. We may now pass to the consideration of the physical properties of light and heat, and endeavour to show how they can be explained consistently with the assumption that light represents compulsive and heat repulsive force; so that we may be more sure of our ground before endeavouring to show in the subjects of physiology and mechanics how the oppositeness of the action of light and heat or of compulsive and repulsive force is turned to account in nature and art to build up animate bodies—just as we have seen already how the same fact is turned to account to build up inanimate masses and bodies—and to supply the wants both mental and physical of the living bodies when they have been built up.

102. We find, then, that light and heat are very generally found together, and that they are radiated, transmitted, reflected, refracted, magnetized, and polarized in the same way; and we have now to

endeavour to explain how this is possible if light and heat respectively represent the compulsive and repulsive forces, which are not similar but opposite forces. We shall see hereafter, that rays of compulsive force perceptible in the form of light rays are always accompanied by rays of repulsive force; and since the one force wherever it enters displaces the other, no impulse of either of the forces in all probability is ever absolutely free from the company of the other force. Nevertheless, we have instances in which organic substances, such as decaying vegetable matter, or inorganic substances, such as quick-lime and pyrites, in decomposing emit a sensible amount of heat unaccompanied by a visible amount of light: in like manner, we have instances in which organic substances, such as fish and wood, or inorganic substances, such as phosphorus, emit in decomposing a visible amount of light unaccompanied by a sensible amount of heat.

Again, we have cases in which heated bodies when removed to a cold place continue for some time to radiate heat unaccompanied by a visible amount of light; and in like manner we have cases in which substances—such as luminous paint, Canton's or Baldwin's phosphorus, or Bologna stone, and many others which have been found by M. Becquerel (Miller's "Chemistry," vol. i., p. 217) to possess the property of phosphorescence—will, after they have

been strongly illuminated, continue for some time, when removed to a dark place, to radiate light unaccompanied by a sensible amount of heat.

Hence so far we have parallel cases both for light and heat in confirmation of the view that the two are opposite and not identical in character.

103. If we now turn back to Fig. 6, at p. 55 we shall perhaps be able to understand without much difficulty how light and heat rays, though opposite in character, can keep together, so far as to be transmitted, reflected, refracted, and polarized in the same way. For we may notice that the shaded spaces which are supposed to represent, as shown in Fig. 5, approximately the spaces occupied in each particle by compulsive force, are contiguous in contiguous particles ; so that if we look at any two contiguous particles we find that the two shaded spaces of the one particle on the side nearest the other particle coincide with or exactly fit on to the two corresponding shaded spaces in the corresponding or nearest side of the other particle ; and since, as defined in paragraph 31, two shaded spaces in continuation of each other between two contiguous particles represent a bond of compulsive force linking the two particles together : we thus see that the particles in any pair of contiguous particles we may select in the crystal (Fig. 6), whether we take them

lengthwise, breadthwise, or depthwise, are linked together by two bonds of compulsive force; and in the same way are kept apart by two struts of repulsive force, which are represented by the unshaded spaces, and which intrude or intervene between the two bonds of compulsive force linking the two particles together.

If now instead of taking a single pair of particles we take three particles in a row in any direction, we see that though the middle particle of the three is connected by two bonds of compulsive force with and separated by two struts of repulsive force from the two particles on either side of it, yet that the two bonds of compulsive force connecting the middle particle with the particle on one side are not continuous with the two bonds connecting the middle particle with the particle on the other side of it, but the continuity of the two sets of bonds is broken in both cases by an intruding strut of repulsive force; so that if an impulse or increment of compulsive force were to travel through the three particles by the bonds of compulsive force by which they are linked together, it would have at the central atom of each particle both to make a détour to get round the intruding strut of repulsive force which by breaking the continuity of the bonds of compulsive force would block its onward progress, and at the same time to displace a portion of this intruding strut of repulsive

force, in order to get from one bond of compulsive force to another. So also we see that the struts of repulsive force separating the middle particle from the two particles on either side of it do not run continuously through the three particles, but the continuity of the two sets of struts is broken in both cases by the intrusion of a bond of compulsive force; so that if an impulse or increment of repulsive force were travelling through these three particles by the struts of repulsive force separating them one from another, it would have to displace at the central atom of each particle a portionof the intruding bond of compulsive force, and would have at the same time to make a détour in order to pass from one strut of repulsive force to another. The fact that impulses of compulsive force do travel through masses by the bonds of compulsive force linking the particles together, and repulsive force impulses by the struts of repulsive force holding the particles apart, seems to be clearly indicated, not only by the fact shown in paragraph 42, that when a bar—which, as we have seen at paragraph 11, may be looked upon as an aggregation of a number of rows of single particles of the full length of the bar—is attached to a mass of matter able to transfer force impulses received from the bar, without motion, then impulses of force acting from a centre situated nearer to the free end of the bar than to the end attached to the

mass, in travelling to the mass of matter through the bar produce, if they are impulses of compulsive force tending to rend the bar from the mass, lateral contraction in the bar, showing that the bonds of compulsive force linking the particles of the bar to the mass have been contracted, and if they are of repulsive force, lateral expansion, showing that the struts of repulsive force separating the particles of the bar from those of the mass have expanded; but is also shown even yet more clearly in the mechanical principle of the Lever, with which it is seen that a bar is practically unable to transfer from one end to the other impulses of force of either kind in a direction transverse to its length, or at right angles to the direction in which the bonds or struts connecting or separating its particles run, though the same bar is able to transfer similar impulses of force of both kinds in the longitudinal direction, or in the same direction as that in which the bonds or struts connecting or separating its particles run; for we find that just in proportion as the length of the bar increases does the portion transferred from one end to the other of a force applied transversely to one end of the bar diminish, so that if two impulses are applied transversely to a bar, one at the end and the other at the middle, then twice as much force will reach the other end of the bar from the force applied in the middle as will reach it from the force applied

at the end; and if the two forces are acting in opposite directions, then the untransferred portion of the force applied at the end will be so great that it will be able to balance the comparatively small portion of force remaining untransferred from a force twice as great applied at the middle. Hence we learn that impulses of force can only travel in the direction in which the bonds and struts connecting or separating the particles are arranged.

If now we isolate from the rest the row of three particles at which we have been looking, and which, as we have seen, are held together each to each by bonds of compulsive force, and kept apart one from another by struts of repulsive force, and look upon the three particles thus connected together in a row as forming a bar, we shall—if we assume that impulses or increments of compulsive force travel only through the bonds of compulsive force by which particles are linked together—be able to understand how if an impulse of compulsive force in the shape of a ray of light impinges perpendicularly upon one end of the bar of three particles, that portion of the ray which falls on the shaded spaces, or spaces occupied by compulsive force in the envelope of the particle at the end on which the ray impinges (see Fig. 7) will enter the particle, whilst that portion of the ray which falls upon the unshaded spaces, representing spaces occupied by repulsive force, will fail

to enter the particle and will be turned back, or, as it is called, reflected. Similarly, if an impulse of repulsive force in the form of a ray of heat falls upon the end of the bar, we can—if we assume that impulses or increments of repulsive force travel only through the struts of repulsive force separating particles one from another—easily understand that the portion of the ray which falls upon the unshaded spaces, representing spaces occupied by repulsive force in the envelope of the particle at the end on which the ray impinges, will enter the particle, whilst that portion of the ray which falls upon the shaded spaces occupied by compulsive force will be turned back or reflected.

Fig. 7

Showing on a very exaggerated scale a bar of three particles of the form shown in Figs. 5 and 6, linked together particle to particle by two bonds of compulsive force indicated by shaded spaces, and separated particle from particle by two struts of repulsive force indicated by unshaded spaces.

If we follow in its passage through the bar the portion of the ray which enters the end particle we see that, after reaching the central atom of the particle, the ray, if it is one of light, must, since its road is along the

compulsive force bonds connecting the particles—which bonds, as we have seen, do not run continuously through from one pair of particles to another—bend round to avoid the repulsive force strut which bars its onward progress in a straight line, and follow, as we may assume, some such direction as that indicated by the dotted line *a a a a* in Fig. 7. On reaching the central atom of the next particle the ray must again bend, to avoid the repulsive force strut which again bars progress in a straight line; and now the bend is in the opposite direction to the previous one, and the ray, following as we assume some such direction as that indicated by the dotted line, gets back into the line it was following when it entered the top particle of the bar. When the ray reaches the central atom of the next particle it again bends back in the same way as with the first particle; and thus it proceeds right through the bar, following a wavy or undulating track, as indicated by the dotted line *a a a a* in Fig. 7.

If the whole or the greater part of the ray which impinges upon the top of the bar passes straight through the bar, and after it emerges from the bar moves on in the same direction as it was moving when it entered the bar, the material of the bar is said to be transparent; and in this way glass is transparent. If the ray, or the greater part of it,

after it enters the bar is twisted and scattered, so that when it emerges from the bar it is broken up and dispersed in different directions, the material of the bar is said to be opaque; thus a metal, such as copper, or iron, or gold, is opaque. And we can easily understand how it happens that most substances are more or less opaque; for if we turn back to Fig. 6 we shall see at once that even when the particles are arranged with perfect symmetry a ray when it enters a fresh substance has, owing to the way particles are linked together, a number of roads open to it by which to travel through, and must inevitably scatter a good deal even under the most favourable circumstances, one part going by one road and one part by another; but when, as must generally be the case, the particles are not arranged with perfect symmetry, the ray has but a very small chance of passing through unaltered; thus we find that even glass, if its particles are twisted or distorted, is no longer perfectly transparent, and if one of its surfaces is roughened, or, as it is termed, ground, the ray is so much scattered on emerging that the glass becomes semi-opaque. On the other hand, we learn that even such opaque substances as gold and silver are not perfectly opaque; for Faraday has shown that a very fine film of gold, of the estimated thickness of $\frac{1}{282,000}$ of an inch, is translucent and transmits green light,

and if heated has the arrangement of its particles so nearly rendered symmetrical that it is able then to transmit white light, or light which is almost white; also that a fine film of silver when strongly heated has the arrangement of its particles so far modified that it becomes translucent ("Researches in Chemistry and Physics," p. 393). And we thus learn that a ray of light, or at least a considerable portion of it, is able to find its way through the first two or three layers of particles on the surface even of so opaque a substance as a mass of gold, and gets gradually scattered or turned back as it endeavours to penetrate more deeply into the mass.

If in the same way we follow a ray of heat, which travels by the struts of repulsive force by which particles are separated one from another, we shall see that the ray of heat will have to make a bend at each central atom to pass round the bonds of compulsive force which block the way, just as the ray of light has, as we have seen, to make a bend at each central atom to avoid the struts of repulsive force which block the way; and thus the path of the heat ray will be a wavy or undulating one, similar to that of the light ray, and following, as we may assume, some such direction as that indicated by the dotted line *b b b b b* in Fig. 7. The bends which the heat ray makes will be in the opposite direction to those the light ray makes, supposing

both rays to pass into the bar by the same side of the same particle.

From the explanation of transparency and opacity given in the case of light rays we shall readily understand how substances may be transparent or opaque to heat rays; also how some substances are transparent or opaque to rays of both light and heat; whilst other substances are transparent to rays of one kind and opaque to rays of the other kind.

We thus see that light and heat if they represent respectively compulsive and repulsive force must necessarily be transmitted and reflected in the same way; and the fact of their coming together from the same direction as we see they so often do, is no proof therefore that they represent the same force.

104. We may therefore now proceed to the study of the Polarization of Light and Heat rays. We have seen then that when a ray of light impinges perpendicularly upon a body the portion of the ray which impinges upon the spaces in the surface particles of the body occupied by compulsive force (shown by the shaded spaces in Figs. 6 and 7) will enter the particle, whilst that portion which impinges upon the spaces occupied by repulsive force (shown by the unshaded spaces in Figs. 6 and 7) will be turned back or reflected; and that

the portion of the ray which enters the body will pass on through it by the compulsive force bonds which connect the particles of the body together, and will finally emerge from the body through the compulsive force spaces in the particles at the surface of the body opposite to that at which the ray entered. So also we have seen that when a ray of heat impinges upon a body the portion of the ray which impinges upon the spaces in the surface particles of the body occupied by repulsive force will enter the body, whilst the portion falling upon the spaces occupied by compulsive force will be turned back or reflected. We have seen also that the portion of the ray of heat which enters the body passes through it by the repulsive force struts which keep the particles of the body apart, and finally emerges from the body through the spaces occupied by repulsive force in the particles at the surface of the body opposite to that at which the ray entered. But if now we turn once more to Fig. 6, p. 55, we shall be able to see at once that if we have two precisely similar crystals, of the form shown in Fig. 6, of the same material and under the same temperature and pressure, and therefore having not only the same number of particles arranged in the same way in each of their sides, but also having the shaded and unshaded spaces on the surface of each side equal in area, and so arranged

that for every shaded space which there may be on the surface of any one side there will be a corresponding shaded space of the same size and in the same relative situation on the surface of every other side, and also for every unshaded space which there may be on the surface of any one side there will be corresponding unshaded space of the same size and in the same relative situation on the surface of every other side; and if we place one crystal upon the other, so that the under face of the one exactly covers the upper face of the other,—then either each shaded space in the under surface of the upper crystal will exactly cover a shaded space in the upper surface of the lower crystal, and each unshaded space in the under surface of the upper crystal an unshaded space in the upper surface of the lower crystal, or else each shaded space in the under surface of the upper crystal will cover an unshaded space in the upper surface of the lower crystal, and each unshaded space will cover a shaded space. We shall see this more clearly perhaps by looking at Figs. 8 and 9; for if A be a particle in the under surface of the upper crystal, and B a particle in the upper surface of the lower crystal, then it is clear that, if the two faces of the crystals exactly coincide, either the particles will be disposed so that the shaded and unshaded spaces of the one respectively cover the shaded and unshaded spaces

in the other, as in Fig. 8, or else the particles will be disposed so that the shaded spaces of the one cover the unshaded spaces in the other, and the unshaded the shaded spaces, as in Fig. 9. It will also be clear that if while the crystals are arranged in the way indicated by Fig. 8, or with shaded space covering shaded space, one of the crystals is turned through an angle of 90°, then the arrangement will be that indicated in Fig. 9, or shaded space will cover unshaded space; but if the same crystal is turned through a further angle of 90°, then the arrangement indicated in Fig. 8 will be reverted to, or shaded space will cover shaded space.

If now after the two crystals have been thus placed one upon the other a ray of light should impinge perpendicularly upon the upper surface of the upper crystal, in such a way that a portion of the ray, after entering the crystal through the shaded spaces, or spaces occupied by compulsive force in the surface particles, passes through it by the bonds of compulsive force connecting the particles in the way already described, it is clear that on emerging from the crystal through the shaded spaces in the particles of the under surface the ray will, if the shaded spaces in the under surface of the upper crystal exactly cover, as in Fig. 8, the shaded spaces in the upper surface of the lower crystal, find a clear road open to it into the lower crystal through the shaded

spaces in the upper surface of the under crystal, and the whole will pass into and through the lower crystal just as if the lower crystal were an integral part of the upper; but if, on the other hand, the shaded spaces in the under surface of the upper crystal cover unshaded spaces or spaces occupied by repulsive force in the upper surface of the lower crystal, as in Fig. 9, it is clear that then the ray on

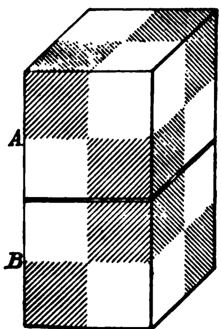

Fig. 8.

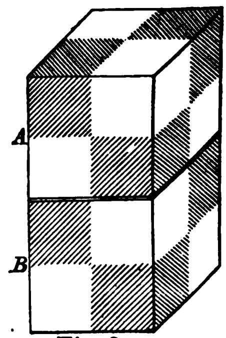

Fig. 9.

emerging from the upper crystal will find its further progress stopped by the unshaded spaces, or spaces occupied by repulsive force lying immediately in its path, and blocking further progress, and the whole of the ray will be turned back or reflected.

But we have already seen that if, when the arrangement of the surface particles of the crystals is that indicated in Fig. 8, with which shaded space covers

shaded space, and a ray which enters at the upper surface of the upper crystal, is able to pass right through both crystals, one of the crystals is turned through an angle of 90°, then the arrangement of the surface particles will be that indicated in Fig. 9, in which shaded space covers unshaded space, and a ray which enters the upper surface of the upper particle will be turned back or reflected at the upper surface of the lower particle, and none of it get through both crystals; also, we have seen that if the same crystal be then turned through a further angle of 90°, the arrangement of the surface particles indicated in Fig. 8 will be reverted to, and shaded space will once more cover shaded space, and a ray entering the upper surface of the top particle will pass right through both particles.

But we have here a clear explanation of the fundamental experiment on which the theory of the polarization of light is founded, namely, that in which a ray of light which passes through two similar plates of tourmaline when they are arranged in a particular position, is shown to be unable to pass through the two plates when one of them is turned through an angle of 90° so as to set the plates crosswise, but is again able to pass if the same plate is turned through a further angle of 90°; for if we assume that when the two plates of tourmaline are so arranged that a ray of light

passes freely through them, the particles at the opposite surfaces of the two plates are in the same position relatively to each other as the two particles in Fig. 8, it is clear that if then one plate is turned through an angle of 90° the particles at the opposite surfaces of the two plates of tourmaline will be brought in the same position relatively to each other as are the particles in Fig. 9, and that any ray of light which may find its way through the first plate will, as we have seen, impinge upon and be turned back by the spaces occupied by repulsive force in the particles at the surface of the second plate, and so no rays will pass through the two plates; also, that if then the plate which has been turned through an angle of 90° is further turned through another angle of 90°, the particles at the opposite surfaces of the two plates of tourmaline will be once more in the same position relatively to ach other as are the particles in Fig. 8, and any ray f light which may find its way through the first e will impinge upon and find a clear road through paces occupied by compulsive force in the par- at the surface of the second plate, and so rays ht will once more pass through the two plates. nd we can also explain in the same way the er experiments exhibited in connexion with the larization of light; for if when two crystals of the m shown in Fig. 6 are placed one upon the other

in such a way that in the particles of the surfaces in contact shaded space covers unshaded space, in the way shown in Fig. 9, and in consequence rays of light which find their way through the top crystal are turned back or reflected at the surface of the under crystal and are unable to pass through both crystals, a thin sheet of mica or some other substance is slipped between the two crystals, it is clear that, owing to the particles of the mica being of a different size and differently arranged from the particles of the crystal, the shaded spaces, or spaces occupied by compulsive force in the under surface of the upper crystal, will partly cover shaded and partly cover unshaded spaces in the upper surface of the sheet of mica, and similarly the shaded spaces in the under surface of the sheet of mica will partly cover shaded and partly cover unshaded spaces in the upper surface of the lower crystal; and hence it is clear that if a ray of light passes through the top crystal and reaches the sheet of mica, a portion of the ray will, on emerging from the top crystal, impinge upon a shaded space in the upper surface of the sheet of mica, and will pass through the mica; and that a portion of that part of the ray which finds its way through the mica will impinge upon a shaded space in the upper surface of the lower crystal, and will thus pass through the lower crystal also, although without the mica it would be im-

possible for any portion of a ray to get through the two crystals. But in this way, clearly, we may explain another of the fundamental experiments in connexion with the theory of the polarization of light, with which the introduction of a film of mica, or some other substance, between the crossed plates of tourmaline through which in the ordinary way no rays of light can pass, suffices to enable some rays to get through both the tourmalines, through which no rays could pass before.

In paragraph 103 we endeavoured to follow and track the path of that portion of a ray of light which by impinging upon the shaded spaces, or spaces occupied by compulsive force, in the surface of a crystal of the form shown in Fig. 6, passed into the crystal; if we now endeavour to track the path of that portion of the same ray which, owing to its impinging upon the unshaded spaces, or spaces occupied by repulsive force, in the surface of the crystal, is reflected and turned back, we shall have little difficulty in understanding how—if the portion of the ray thus reflected from the shaded spaces on the surface of the crystal should subsequently impinge perpendicularly upon the surface of another crystal precisely similar to the crystal from which it was reflected, but disposed in such a way that, if the surface from which the ray was reflected and that upon which it subsequently impinges were brought

close together, the unshaded spaces of the surface from which the ray was reflected would be exactly covered by the shaded spaces of the surface upon which the ray impinges—every portion of the reflected part of the ray must then impinge upon a shaded space on the surface of the other crystal, and so impinging the whole of it would enter and pass through the second crystal, and no portion of it would be reflected. But in this way, clearly, we can explain another of the fundamental experiments shown in connexion with the theory of the polarization of light, with which a beam of light after it has been reflected is enabled so to impinge upon a plate of glass as that the whole of the beam shall be enabled to pass into the glass, and none of it be again reflected. The fact that with this experiment the beam before it passes into the glass is reflected at a certain angle, and not perpendicularly, does not materially affect the case; for we can understand that if, as will generally, if not always, be the case with a solid, the shaded spaces, or spaces occupied by compulsive force, are greater than the unshaded spaces, or spaces occupied by repulsive force, the effect of causing a beam of light to impinge upon the surface of any solid at an angle less than a right angle will be to contract, so as to speak, the roadway open to the beam through the solid, and thus, by causing a greater proportion of the beam to be reflected, to

equalize in effect more nearly the shaded and unshaded spaces.

We have thus explained the principal experiments which, with various modifications, are usually exhibited in connexion with the theory of the Polarization of light. But it is perfectly clear that if repulsive force is substituted for compulsive force as the medium through which the rays travel, and compulsive for repulsive force as the medium by which the rays are reflected, the same explanation exactly will apply to the case of heat rays, just as well as to light rays; and when, then, we find that light and heat rays can both alike be polarized, and that the same experiments can be used with radiant heat rays to show the Polarization of heat (Tyndall on "Light," pp. 183—185) as are used with light rays to show the polarization of light, our confidence in the accuracy of the explanation is increased.

We have thus found in the fact that both light and heat rays are transmitted, reflected, and polarized in the same way, proof of the accuracy of the view that light represents compulsive, and heat repulsive force. We may now pass on to study Refraction and Diffraction.

105. The assumption (Tyndall on "Light," p. 110) that the refraction—or change of direction which a beam of light always undergoes when passing from

one medium into another of different density, provided that the direction of the beam is not perpendicular to the surface at which the transition takes place—is due to the rays on one side of the beam being retarded, owing either to their reaching sooner the surface of a substance in which the ray travels at a lower velocity than it does in the other substance, or to their emerging from a substance in which they travel at a low velocity later than the rays in the other side of the beam do, and to the other side of the beam in consequence swinging round towards the retarded side, seems to imply a certain amount of coherence between the rays or opposite sides of the rays of which the beam is made up. And though a bar of any solid material, owing to the coherence of its particles, would, no doubt, swing round if one side of it were moving faster than the other, we have apparently no proof that the rays or opposite sides of the rays of which a beam of light is made up have sufficient coherence between themselves to rotate the beam or the rays if one side is moving faster than the other. We therefore feel compelled to see if any other explanation of Refraction can be found.

If, then, we turn once more to Fig. 6, it will be apparent that, if a ray of light or of heat impinges perpendicularly upon the surface of a body in which, as in the crystal shown in Fig. 6, the particles are

set perpendicularly to the surface, and enters the body, that the ray in passing through the body will compress or expand, as the case may be, the particles in one direction only, but if the direction of the ray instead of being perpendicular to the surface is inclined at an angle to it, the compression or expansion, as the case may be, must take place in two directions, at right angles to each other, one being perpendicular and the other parallel to the surface. And we may perhaps obtain practical proof that this, or the converse of this, is the case; for if we half fill a plain uncut glass tumbler with water, and then hold a cherry or some other small fruit by its stalk in such a way that the fruit is immersed to the depth of about an inch in the water in the middle of the tumbler, we shall, if we look sideways down at the cherry in such a way that a straight line drawn from the cherry to the eye will be inclined at an angle of about forty-five degrees both to the surface of the water and to the side of the tumbler, see two cherries, one plainly produced by a ray which is propagated by a compression of the particles in a direction perpendicular to the surface of the water, and the other by a ray propagated by a compression of the particles in a direction perpendicular to that of the other ray, or parallel to the surface of the water, and both rays reaching the eye by the refraction, or bending in a direction away

from the perpendicular, which occurs when the ray passes into the air.

If then, after traversing a medium in which the particles are able to offer just as much resistance to a force tending to compress them in one direction as in another, a ray of light passes into another substance in which the particles are able to offer more resistance to a force tending to compress them, in a direction parallel to the surface than in a direction perpendicular to the surface, it will be plain that, if the ray impinges upon the surface of this substance in such a way that its direction is not perpendicular to the surface, and that it must, if it enters the body, compress the particles of the substance in two directions—viz., one perpendicular, and one parallel to the surface,—then the ray must be bent towards the direction in which it meets with the least resistance, and consequently towards a direction perpendicular to the surface. And if after passing through this substance in which, owing to the resistance to compression being greater in a direction parallel to the surface than in a direction perpendicular to the surface, the ray is bent towards a direction perpendicular to the surface, the ray emerges into another substance, in which the particles are able to offer more resistance in a direction perpendicular to the surface than they are in a direction parallel to the surface to a force tending

to compress them, it is plain that the ray, if the surface at which it emerges is parallel to that at which it entered, will now be bent away from the direction perpendicular to the surface, instead of towards it as before. In this way we may explain in a simple way why a ray which passes from a less refracting into a more refracting medium, when its direction is not perpendicular to the surface at which it enters the new medium is bent towards a direction perpendicular to that surface; and if it passes in the same way from a more refracting to a less refracting medium, it is bent away from a direction perpendicular to that surface. If we suppose that in air particles about a solid or liquid surface the resistance to compression is greater in the perpendicular than in the parallel direction—as it well may be since a film of the particles must be more or less flattened out; and that in a piece of glass the resistance to compression is greater in a direction parallel to the surface than it is in a direction perpendicular to the surface—as it well may be, seeing that a sheet of glass, as already pointed out in paragraph 100, though it allows both rays of light and of electrical force which impinge perpendicularly upon its surface to pass through, refuses passage to and turns back rays both of light and of electrical force which are parallel or nearly parallel to its surface,—it will be plain that a ray of

light passing from air into glass when the direction of the ray is not perpendicular to the surface of the glass, will be bent towards a direction perpendicular to that surface; similarly, if the ray passes from glass into air when its direction is not perpendicular to the surface of the glass, it will be bent away from the perpendicular. In a similar way we may explain how refraction occurs with other substances also. These are the ordinary facts connected with Refraction, and they serve, as we may plainly see, to give us an insight into the structure of substances.

It is plain that heat rays can be refracted in precisely the same way that light rays are refracted; and accordingly we find light and heat rays brought to the same focus with a lens, by Refraction.

106. We have seen that Refraction occurs, with a substance in which the particles are able to offer a greater amount of resistance to compression in one direction than in another, when a ray of light enters the substance from a direction which is not perpendicular to the surface, and when in consequence the ray in passing through must cause compression of the particles in the two directions in which their power of resisting compression is dissimilar. But if we turn again to Fig. 6, we shall see that, since there are three axes to a particle, that the particles of which a crystal is built up may be so constituted

that their power of resisting compression may differ in three directions—or in other words, lengthwise, breadthwise, and depthwise the power of the particles to resist compression may be different; and we shall see also that the direction of a ray may be so inclined to the surface of a crystal that in order to pass through the crystal it must compress the particles in three directions. And it is easy then to see that if particles have in each of the three directions in which a ray compresses them a different power of resisting compression, the ray must be refracted in two directions, or undergo double refraction, as it is called, dividing into two separate rays, which will each of them produce an image of the object from which the rays proceed; just as in the experiment with a cherry suspended in a glass tumbler half full of water, we saw that the rays from the cherry divided in such a way that one part reached the eye by refraction from the surface of the water and the other part reached the eye by refraction from the side, and two images of the cherry were in consequence formed.

If this is the right explanation of Double Refraction, it is plain that heat rays as well as light rays can undergo double refraction; and we shall not then be surprised to learn that the double refraction of heat can be experimentally demonstrated (Tyndall on "Light," p. 186).

107. Passing now to Diffraction, we shall easily see that if a ray of light represents compulsive force and a ray of heat repulsive force, a ray of light or of heat will have to open a passage for itself by displacing a sufficient amount of the opposite force, just as we have seen in paragraph 42, that other efforts or impulses of force have to open passages for themselves. But since a ray of light must produce compression, and a ray of heat must produce expansion, it is also plain that rays of light and of heat cannot pass together into the same particle, but one must follow the other, a compressive phase succeeding an expansive one, or an expansive a compressive one; and if, owing to the paths of two rays crossing, the expansive and the compressive phases of two separate rays reach the same particle at the same time, the two rays will obliterate each other entirely if their paths are nearly parallel, or, otherwise, partially. Hence, if the paths of two rays starting—so that one is half a wave's length, or any number of half waves' lengths, behind the other—from points close together, cross each other at some distance from the points from which the rays start, the rays will obliterate each other, compression neutralizing expansion. Whilst if the rays under the same circumstances start evenly, or with one a whole or any number of whole waves' lengths behind the other, the rays will intensify each other, com-

pression being superadded upon compression and expansion upon expansion. In this way it is possible to explain all interference and diffraction phenomena with which fringes are formed when one set of waves cross the path of another set; since fringes indicate by the dark spaces in them the points where rays, starting half or any number of half waves' lengths behind other rays, cross the paths of those rays, and, by the bright spaces, the points where one set of rays is a full or any number of full waves' lengths behind the other set.

108. With regard to the Magnetization of light, we have seen that a magnet takes repulsive force from, and communicates compulsive force to, the particles of substances which come under its influence, and thus produces compression in the particles towards the pole of the magnet. Hence, if a ray of light or of heat passes in a direction transverse to the poles of the magnet—through any substance which at the time is strongly acted upon by a magnet, it is clear that the ray will be bent or distorted in passing through the substance whose particles are thus compressed and bent round the poles. We find accordingly that rays of light and heat can both be magnetized (Tyndall on "Light," pp. 145 and 187).

109. Passing now to the consideration of the subject of spectrum analysis, we may notice first

that the opposite surfaces of prisms are not parallel to each other, and hence that there are two ways in which the particles in a prism may be uniformly arranged, namely, either in rows not perpendicular to the surfaces but continuous right through the prism, or in rows perpendicular to the surfaces and not continuous through the prism. We may notice also that if the particles are arranged in continuous rows which are not perpendicular to the surfaces, then the exposed ends of the surface particles cannot be square to the rows, or if square, must in cross section project one beyond the other in a series of steps, so that a portion of one side, as well as the end of each surface particle, will be exposed.

Now we know that when the surface of a piece of glass is roughened, or scratched, images of objects are not discernible through such a piece of glass, owing, plainly, to the particles of the glass at the roughened surface being in contact with a larger number of air particles than the particles of a smooth surface are, and to the rays of light which emerge at the roughened surface in consequence finding, and scattering over, a great number of roads. And it is clear that if, in a prism, either the ends of the surface particles are not square to the rows, or if they are arranged in steps up the surfaces so that a portion of one side as well as of the

end of each of the surface particles is exposed, then the surface particles in either case will be in contact with a greater number of air particles than they would be if their ends were square with the rows and all level one with another; and therefore any rays of light which pass through such a prism will, on emerging, find a greater number of roads open to them than they would find if the ends of the particles were square with the rows and all level one with another, and will therefore to some extent scatter, though they will, since the particles at the surface of the prism are uniformly arranged, scatter uniformly, and not irregularly as do rays of light which emerge from the surface of roughened glass.

It is clear, also, that, if the particles in a prism are arranged in rows perpendicular to the surfaces, and not continuous through the prism, rays of light which pass through the prism will, on passing from one row of particles into another, find more roads open to them than they would find if the rows were continuous, and will scatter.

We thus see, theoretically, the extreme probability that rays in a beam of light will scatter if the beam passes through a prism: and we find in practice that when a beam of sunlight is passed through a prism the rays so far scatter as to produce a spectrum very much wider than the original beam, and made up of a series of differently coloured bands of

light, of which the first is a red band, the next an orange one, the next yellow, the next green, the next blue, the next indigo, and the last violet. Now we learn in regard to the spectrum, as Professor Stokes first showed, that when the spectrum is allowed to fall on certain substances a band of coloured rays, called the ultra violet rays, becomes visible beyond the violet band which is ordinarily seen; and also that under similar circumstances a band of ultra red rays is sometimes visible beyond the red band which is ordinarily seen. Further, we learn that if the temperature of the spectrum is examined it is found to be, as Herschel first showed, lowest in the violet portion of the spectrum and highest in the ultra red, gradually rising from the violet to the red, and reaching a maximum at a point some distance beyond the visible red end of the spectrum. We learn also that if the chemical activity in bringing about the combination of gases of the rays at different parts of the spectrum is examined, it is found to be least of all in the red, and greatest in the ultra violet portion of the spectrum, gradually rising until it reaches a maximum at a point some distance beyond the violet end of the visible spectrum. We have already seen that chemical activity is due to compulsive force, and if then light rays, as impulses of compulsive force, pass, as stated in paragraph 103, by the bonds of compulsive

force which link particles together and therefore through different roads from those by which heat rays, as impulses of repulsive force travelling by the repulsive force struts which separate particles one from another, pass, we can without much difficulty understand that the scattering or dispersive effect of the prism may be so far different in the two cases as to accumulate rays of one kind at one end, and rays of the other kind at the other end of the spectrum. But here our attention will be arrested by the fact that this separation or differentiation of the two kinds of rays is attended by a gradual change of colour in the spectrum, so that at the end where the temperature is greatest and chemical activity is least the colour is red, and at the end where the chemical activity is greatest and temperature least the colour is violet: and if now for chemical activity we substitute compulsive force, and for heat repulsive force, we shall thus have violet rays representing waves propagated by a large amount of compulsive attended by a small amount of repulsive force, and red rays representing waves propagated by a smaller amount of compulsive attended by a larger amount of repulsive force; also yellow rays from the middle of the spectrum, intermediate between the red and the violet, representing waves in which the amounts of the two forces are intermediate between the a [illegible] iolet and red rays.

In dealing with Diffraction we have seen in paragraph 107 that light and heat impulses, since the one produce compression and the other expansion, cannot travel together through the same particle, and that one must follow the other. We can therefore understand that if in a ray the amount of compulsive force is great and the amount of repulsive force is small, the periods of compression in the particles through which the ray travels will be long and the periods of expansion short; and that if the amount of repulsive force is great and the amount of compulsive force small, the periods of expansion will be long and the periods of compression short. Hence, in the passage of violet rays the phases of compression will be long, and the phases of expansion short, and in the passage of red rays phases of expansion will be longer, and phases of compression shorter; whilst in yellow rays the phases will be intermediate between those of the other two rays. Hence, if we assume that rays of white light represent the greatest amount of compulsive force which the eye is capable of appreciating, attended by, comparatively speaking, a very large amount of repulsive force, we shall be able to understand how it is possible for white light to be decomposed in a prism into a spectrum of different colours, by the greater part of the compulsive force of the white rays being relegated to the violet end,

and the greater part of the repulsive force to the red end of the spectrum.

Since, a portion of each ray, whether of light or of heat, which impinges upon the surface of any substance is usually reflected by the particles at or near the surface; and since out of the remaining portion which enters the substance a part is sometimes absorbed in the work of promoting changes in chemical combination, and a portion of the opposite force displaced by it given in exchange and another part scattered, it will not be difficult to understand how, by reflecting or absorbing or scattering a greater proportion of force of one kind than they do of the other, masses of matter can effect changes in the colour of the rays of light they transmit or radiate. Hence also we can understand how, by reflecting more repulsive force or less compulsive force than substances ordinarily do, it is possible for some substances, such as sulphate of quinine, so to draw out, by increasing the proportion of repulsive force, the ultra violet rays of the spectrum as to render them visible, although ordinarily, on account of a deficiency of repulsive force they cannot be appreciated by the eye: and in this way the phenomenon of Fluorescence may be explained. Similarly, we can see that it may be possible for some substances, by reflecting a greater proportion of compulsive force or a smaller amount

of repulsive force than other substances do, to render the ultra red rays visible, which, owing to a deficiency of compulsive force or an excess of repulsive, are not ordinarily appreciated by the eye; and in this way the phenomenon called by Dr. Tyndall calorescence, may be explained.

110. We see now the importance to an animal or plant of the colour of different parts of its body, leaves, or flowers, since this enables the various parts to assimilate force in kind or amount suitable for the stimulation of the different sets of nerves or muscles, or for the elaboration of the secretions on which the growth of the animal or plant, or the reproduction of its kind, depends, and to reject force which in kind or quantity is unsuitable. Hence, every spot and mark—on skin, hair, feather, scale, egg, leaf, flower, or seed—has its particular use.

111. Since a solid is luminous at a much lower temperature than a gas is, owing to the large amount of compulsive force present in the particles of a solid, as shown in paragraph 17, it is clear that rays which are not luminous when passing through air or gas, may, if they impinge upon a solid, produce, by displacing compulsive force from the solid, a luminous image.

112. We thus find in a consideration of all the properties of light and heat, evidence to support the view that the one represents compulsive and the

other the opposite repulsive force; and we may now endeavour to see how the oppositeness of the action of these two forces is turned to account in Nature in building up living forms, and supplying the wants of the body and of the mind.

CHAPTER VI.

PHYSIOLOGY.

113. HITHERTO we have been dealing with lifeless masses of matter. We have seen that the first stage in the process of the formation of such of these masses as are liquid or solid compound substances consists in the formation of groups, in each of which the different kinds of particles of which the mass is made up marshal themselves in regular order, each having and taking its appointed place; so that each group, when it is complete, contains not only the same number of particles, but also the same number of each of the several kinds of particles, in the same positions relative to one another, that every other group contains.

The second stage in the formation of a compound solid or liquid mass consists in the groups of particles formed in the first stage transferring repulsive force to, and taking compulsive force from, the particles of substances contiguous to them, until each of the groups parts with so much repulsive force, and obtains so much compulsive force, that it

passes from the liquid to the solid, or from the gaseous to the liquid state, and the mass as a whole assumes the liquid or the solid form. This we know from the fact that to liquefy a gas it is necessary, as we have seen in paragraph 18, to abstract repulsive force in the form of heat, and apply compulsive force in some way.

We have seen also that when a solid mass or a liquid mass built up out of these groups of particles comes in contact with another mass in the liquid state also built up of groups of particles, in many cases it breaks up and dissolves, if a solid, in the liquid mass, or if a liquid, diffuses itself through the other liquid mass; and the groups of particles of the two masses then arrange themselves in regular order in groups of groups throughout the solution or mixture, just as single particles arrange themselves to form groups of particles; and just as we have in some compound substances groups made of three or four different kinds of particles, so also may we have some solutions containing three or four different kinds of compound substances with their respective groups of particles, grouped together in regular order just as single particles are grouped.

We have seen, too, when particles or groups of particles of several substances are grouped together by the process of solution or diffusion, and force is applied, either in the form of heat or light or in that

of an electric current, to the solution, or mixture that changes generally occur by which the particles are drawn closer together or driven further apart, and a rearrangement of the particles in the groups is effected by some of the particles changing places with others, whereby some of the particles are displaced from the groups of one or other of the compounds, and fresh compounds with new groups are formed. We have seen, too, that when changes occur by which particles are displaced from the groups of particles of any compound, an emission of force, either compulsive or repulsive, takes place.

We have seen, too, that when particles or groups of particles, under the action of compulsive force, draw together in some portion of a liquid or a gaseous mass, and assume the solid condition, they often so dispose themselves as to build up a number of perfectly regular bodies or crystals, which, though generally of a simple form, are sometimes of compound forms, such as the cross adopted by crystals of staurotide (Dana's "Mineralogy"), or the arrow-head form adopted by crystals of gypsum (ibid.), or the branching or plumose form adopted by other crystals, of which we may see beautiful examples any frosty day in the ice crystals which form upon the panes of glass in our windows; or sometimes, as in the case of asbestos, are in the form of fibres, so fine and tough that cloth

can be manufactured with them; or sometimes, as in the case of mica, are in the form of laminæ or plates, so large, so clear, and so thin, that they can be used in place of glass.

We now pass to living forms, which are, as we find, built up principally of carbon, hydrogen, oxygen, and nitrogen particles, though they often contain in addition one or more of the other elementary substances, such as chlorine, calcium, magnesium, sodium, sulphur, phosphorus, iron, silicon, and some other particles, but contain no particles other than those found in lifeless matter; and thus as far as their composition is concerned the organic compounds, or substances of which living matter is made up, do not differ from the inorganic compounds, or those of which lifeless matter is made up (see Kekule's remarks quoted in Roscoe's "Chemistry," vol. iii., part 1, p. 32).

We find, also, that all organic compounds formed in nature contain carbon and hydrogen, and most of them also oxygen, and that the same laws of combination regulate the formation both of organic and inorganic compounds (Roscoe's "Chemistry," vol iii., part 1, pp. 31—34). We notice, however, in the inorganic compounds the almost infinite variety of compounds formed with carbon and hydrogen particles by merely varying the number of particles in the groups or adding one or more particles of

some other elementary substance to each group. Thus we find in inorganic chemistry the following series of substances known, viz. Methane CH_4, Ethane C_2H_6, Propane C_3H_8, Butane C_4H_{10}, Pentane C_5H_{12}, Hexane C_6H_{14}, Heptane C_7H_{16}, Octane C_8H_{18}, and so on, in which the gas Methane, which stands first, has in each of its groups of particles one particle of carbon united to four of hydrogen; and each succeeding substance has groups which differ from those of the preceding substance by containing one additional particle of carbon and two of hydrogen; thus, in Ethane the groups consist each of two particles of carbon united to six of hydrogen, and in Propane of three particles of carbon united to eight particles of hydrogen, and so on. Again, we find another series, viz. Ethylene C_2H_4, Propylene C_3H_6, Butylene C_4H_8, Pentylene C_5H_{10}, Hexylene C_6H_{12}, and so on, in which, Ethylene, standing first, has in each of its groups two particles of carbon united to four particles of hydrogen; and each succeeding substance differs from the one preceding it in the same way as the members of the other series differed, viz. by containing in its groups one additional particle of carbon and two of hydrogen. Again, parallel to the first of these two series we find a series of alcohols: Methyl Alcohol CH_4O, Ethyl Alcohol C_2H_6O, Propyl Alcohol C_3H_8O, and so on, in which Methyl Alcohol, standing first, has one par-

ticle of carbon, four of hydrogen, and one of oxygen in each of its groups, and thus differs from Methane only in having one additional particle of oxygen in each of its groups; and each succeeding Alcohol in the series differs from the one preceding it by having one additional particle of carbon and two of hydrogen in each of its groups, and from the parallel substance in the first series by having one additional particle of oxygen in each of its groups. Also parallel to the second series we have a series of fatty Acids: Acetic Acid $C_2H_4O_2$, Propionic Acid $C_3H_6O_2$, Butyric Acid $C_4H_8O_2$, and so on, in which Acetic Acid, standing first, has two particles of carbon, four of hydrogen, and two of oxygen in each of its groups, and thus differs from Ethylene in the other series only in having two additional particles of oxygen in each of its groups; and each succeeding Acid differs from the one preceding it by having one additional particle of carbon and two of hydrogen in its groups, or from the parallel substance in the other series by having two additional particles of oxygen in its groups (see Roscoe's "Chemistry," vol. iii., part 1, p. 37). The series referred to are being constantly extended, and the first of them already reaches to Hecdecane $C_{16}H_{34}$, in which the groups consist of sixteen particles of carbon united to thirty-four of hydrogen, and other series too are known; so that the number of hydrocarbons is very striking.

We shall find in the living forms that the particles arrange themselves in groups and groups of groups, in the same way as they do in gases or in solutions in lifeless matter; also that the groups collect together, and form solid masses of regular form in the shape of cells in much the same way that groups of particles of lifeless matter collect together and form crystals of regular form, or amorphous masses of matter, or forms intermediate between the two. But here the resemblance between the crystal and the cell ends; for although a crystal, as we have seen in paragraph 38, may be fed by supplying it continually with fresh supplies of the solution in which it was originally formed, and will, if proper precautions are taken, continue to grow for some time; and though the living form also grows if it is fed; the living form grows altogether from the inside while the crystal grows from the outside. We may trace the growth of the living form from the inside throughout its development, from the formation of the first cells from which all living forms are developed, to the completion of the frame, with a trunk and extremities in the shape of roots and branches, or a body with a head and limbs.

We find from Sachs' "Text-Book of Botany," that a vegetable cell is developed in the following way: first a mass of protoplasm collects and covers itself with a skin of cellulose, generally developing a

nucleus; then as the cell grows the protoplasm disposes itself as a lining to the outer skin of cellulose, thus forming a sac, inside of which a watery fluid, called cell sap, collects; afterwards, as the cell continues to grow the protoplasm diminishes, but the cell wall gets thicker, and the cell sap increases; finally, when the whole of the protoplasm has disappeared the cell ceases to grow. And we may therefore assume that the cell grows by its walls enlarging and thickening at the expense of the protoplasm inside the cell, and that the cell sap simply takes the place of the protoplasm which has been used up.

Now we learn that protoplasm is a mixture of albuminous compounds with water; and according to Miller's "Chemistry," part. iii., sect. 1, p. 3, Albumin has approximately the formula $C_{72} H_{112} N_{18} SO_{22}$, or, in other words, each of its groups consists of seventy-two particles of carbon united to 112 particles of hydrogen, eighteen of nitrogen, one of sulphur, twenty-two of oxygen. We learn also from the percentage composition, given in Carpenter's "Human Physiology," p. 59, of the various forms of Albumin, such as egg albumin, serum albumin, fibrin, globulin, &c., that the different forms of Albumin closely resemble each other, and we may perhaps therefore assume that they belong to some series in which the different members are even more closely allied to one another than are those of the

paraffin, or methyl alcohol, or fatty acid series. At all events, all the forms of Albumin are very unstable, and easily decomposed. Cellulose, on the other hand, of which the cell wall is chiefly made up, has the same formula as Starch, or $C_6H_{10}O_5$, or its multiples; and if then we assume the multiple for Starch to be twelve, each group of particles in Starch will consist of seventy-two particles of carbon, 120 particles of hydrogen, and sixty particles of oxygen, or thirty-eight particles of oxygen more, and eighteen particles of nitrogen and one of sulphur less, than an Albumin group. Thus we see that in Starch the eighteen particles of nitrogen and the single particle of sulphur of one of the Albumin groups have been replaced by thirty-eight particles of oxygen; or in other words, the sulphur particle and each of the nitrogen particles have been replaced by two particles of oxygen. Thus the oxygen has replaced the sulphur and the nitrogen in the proportion in which it combines with those substances. We see, therefore that to convert albumin into cellulose or starch we have, if we neglect the hydrogen, only to replace nitrogen and sulphur by oxygen.

Now we know that albumin is always coagulated by heat; in fact, any one may satisfy himself on this point by noticing how the albumin, or white, as we call it, of an egg is coagulated when the egg is boiled.

And we find, from Sachs' "Text-Book of Botany,"

that the protoplasm of living plants is generally watery, and is on the inside differentiated into layers, which differ from each other in chemical composition and in the amount of water they contain in such a way that the innermost layer is the most watery one. Hence we may perhaps be able to follow the successive steps by which an inanimate mass, made up of groups of albumin and water-groups of particles, is converted into a living cell.

For if we assume that after a minute mass has been formed by the grouping together of albumin and water groups of particles, the mass is exposed to the action of excessive heat for a sufficient time just slightly to coagulate the albumin at the outside—exactly as we sometimes see, in a lightly boiled egg, the white or albumin at the outside close to the shell is coagulated, whilst all the rest of the white inside remains clear and liquid—and that then, when the albumin at the outside has been thus slightly coagulated, the mass passes on to some other situation where a moderate amount of light and heat reaches it, it is clear that the effect of compulsive force, in the form of light acting upon the cell and causing contraction in it, will be to squeeze out some of the water-groups of particles, and thus to form next the coagulated outside layer a layer less watery than the innermost part of the cell. It is also clear that the after-effect of the application of repulsive

force in the form of heat to the cell of protoplasm, thus coagulated on the outside and containing fluid in the inside, will be to expand the outside, causing a partial vacuum in the inside: owing to which partial vacuum some of the groups of particles of the liquid or gaseous masses surrounding the cell will pass into the interior of the mass of protoplasm forming the cell, and thus also carbonic acid gas may be supposed to pass into the cell. If the cell were now again exposed to the action of compulsive force in the form of light so as to be once more contracted, a portion of the liquids and gases which had passed into the interior when the protoplasm was expanded would be expelled, being forced through the contracted walls of protoplasm forming the sides of the cell. But though the groups of particles of gases or liquids will pass in easily enough between the groups of particles in the expanded walls of protoplasm—just as the particles of hydrogen gas can pass through the pores of a platinum or palladium tube when red hot, though they cannot pass through the tube when cold—yet when the protoplasm is much contracted it may plainly happen that the groups of particles of liquids or gases will have great difficulty in passing out; and it may thus come to pass that though the more condensible oxygen particles in the carbonic acid gas groups may pass out, the less condensible

particles of carbon will fail to get out; and thus the carbon particles will be sifted out of the carbonic acid gas which entered the cell.

This explanation of the way in which, in plant cells, the carbon particles are separated from the oxygen particles in carbonic acid groups of particles, is not merely an imaginary one, for Faraday, in "Researches in Chemistry and Physics," p. 219, notices Mr. Gordon's experiment, in which it was shown that when oil gas, compressed to thirty atmospheres, was allowed to escape through a very small aperture, a deposit from the gas of black carbonaceous matter took place if a sheet of white paper or other substance were held so that the gas in issuing rushed against it. And here clearly we have an instance of carbon particles being actually sifted out from a gas in passing through an aperture. But Faraday notices a still more striking instance of this sifting out of carbon particles from a hydrocarbon gas; for he states that it was found at the Royal Institution, that when oil gas was condensed at high pressure, and a perfectly clear and transparent fluid obtained, this clear fluid, if it was placed in corked bottles, was in many cases transformed by spontaneous evaporation through the corks into a heavy brown almost solid substance, like honey or treacle. Here then, plainly, we have the bottle-corks playing the same part as that assigned to the walls of protoplasm

in plant cells in sifting out carbon particles from gas, much as grain is sifted from small seeds in a sieve.

We may assume that some of the oxygen particles thus separated from the carbon particles, will, being in the nascent state, as they pass through the pores of the protoplasm, displace the eighteen nitrogen and the single sulphur particles from some of the albumin groups at the outside of the walls of protoplasm of the cell, and, converting the albumin into cellulose, thus form cellulose membrane in the outside of the mass of protoplasm. And that others of the albumin groups in the interior of the mass of protoplasm will be converted by the nascent and active oxygen particles into starch, which has, as we have seen, the same composition as cellulose; and in this way the formation of starch, which always takes place in the interior of the protoplasm of a cell exposed to light, may be accounted for. Also that some of the oxygen will combine with the displaced sulphur and nitrogen particles and some will escape as free oxygen: whilst the carbon particles left behind in the cell, being in the nascent state, will combine with some of the carbo-hydrates or fats which, according to Sachs, are generally contained in a mass of protoplasm ("Text-Book of Botany," p. 37, Trans.), and will afterwards combine to form albumin with a portion of the nitrogen and sulphur

displaced in the interior of the cell by the oxygen from the albumin groups to form starch.

On being once more exposed to heat the sides of the cell would again expand, and take in more carbonic acid gas and more liquids; and these would again, when the cell was once more exposed to the action of light, be in part expelled, with the result of again sifting out the carbon particles from the carbonic acid gas, and setting free oxygen particles to form more cellulose and starch, and thus enlarge and thicken the cell walls. The acids formed in the interior of the cell by the displaced sulphur and nitrogen in the presence of the fluids inside the cell, would decompose foreign bodies which might pass into the cell, and facilitate the assimilation of their particles or their subsequent expulsion. In this way a cell which is favourably situated for receiving supplies may form secretions of the materials required by other cells, and by discharging, when it contracts, these secretions into sap which will be imbibed by other cells, furnish cells which are less favourably situated with the materials they require to enable them to grow; thus the leaf cells of a plant may secrete starch and supply this material to the plant, while the root cells secrete the different salts which the plant requires.

Thus all growth in a vegetable cell is due to the action of heat in producing expansion in the

cellulose and albuminous walls of the cell, and thereby making room inside the cell for the gases and fluids required for its growth to pass in, and to the subsequent action of light in producing contraction in the walls of the cell, and thereby extruding from the cell, and depositing in the proper position, the material required to build up or extend the cell walls. The expansions and contractions of course succeed each other with almost infinite rapidity.

We may assume that a cell exposed to strong light will be contracted more than a cell which receives but little light; and that in consequence the cell under strong light will have thicker and denser walls, but will grow more slowly than the other cell. In this way the fact noticed by Sachs ("Text-Book of Botany," Trans., p. 676), that growing stems or leaf-stalks, which receive a much greater amount of light on one side than on another, curve towards the side exposed to the more intense light, by the slower growth of the illuminated side, and in the same way the fact that light, by the greater amount of contraction which it induces in the cell, is necessary to enable the cells to sift out carbon particles from carbonic acid gas, and secrete starch, may be explained.

A single cell when favourably situated is thus complete in itself; and we have plants, such as the yeast plant, consisting of rows of simple cells (see

Huxley on "Yeast"). But since changes go on inside the cell by which, as we have seen, the rearrangement of the particles in the groups of particles of some of the compounds inside the mass is effected, and fresh compounds are formed, and, amongst others, the albuminous compounds of which protoplasm is constituted, it does not seem difficult to understand the way in which a single cell in full vigour attaches to itself, by a process of exogenous germination (Carpenter's "Physiology," p. 65), other masses of protoplasm, which in their turn develop into cells; for if, owing to one side of the cell receiving more force than another, the growth of the cell walls is not uniform, it is easy to understand that rupture of the cell walls may occur at some point under the action of repulsive force developed by the changes which go on inside the cell, and that such rupture may be followed each time by the extrusion of a mass of protoplasm, which will subsequently be attached to the outside of the cell by compulsive force also developed by changes inside the cell, and form a new cell, being coagulated on the outside by the extruding force; or if the mass escapes, it may as a spore develop into a cell independently. When a cell has in this way surrounded itself with younger cells it must, if it continues to grow, receive the fluids and gases necessary to its growth, and discharge secreted or waste fluids either through or

into the cells surrounding it, or by pores or openings left between the cells; and thus a system of capillary or venous circulation will naturally be set up. The cells which the original cell has attached to itself will in their turn attach to themselves masses of protoplasm, which will also develop into cells; and thus the plant will grow. Since the plant receives moisture, and the different salts which it requires, from the earth, and carbonic acid, nitrogen, and other gases from the air, the cells at the two ends of the plant will differentiate, those at the one end fitting themselves to imbibe moisture and secrete salts from the earth, and eventually forming a root, those at the other end fitting themselves to inhale gases from the air, and to secrete starch, and eventually forming leaves. Branches will naturally be formed, both at the root end and at the top, at points varying with the form of the original cell, where a marked development of force takes place, just as branches are formed in some compound crystals. The cells which have ceased to grow in the stem and branches will on the inside, by their thick dense walls of cellulose, form woody fibre, which will furnish the necessary support to enable further extension to take place; and at the same time, being porous, will furnish a connected series of tubes through the roots, stem, and branches, by which fluids can circulate, conveying starch elaborated in

the leaf cells down to the roots, and salt secretions prepared in the root cells up to the leaves; and those too which have ceased to grow on the outside will form a dense covering in the form of bark, to protect the young cells and prevent evaporation in the sap.

A marked circulation of sap must take place in the autumn, when the tree as a whole contracts under the action of compulsive force in the form of light and diminished heat, and in the spring, when the tree as a whole expands under the action of an increase of repulsive force in the form of returning heat; there must also be a daily circulation arising from the same cause; and in fine weather a constant circulation, due to one side by day and one end by night receiving more light or heat than the other side or end.

It is easy to see that when a plant is in full vigour, and its leaves and roots are actively engaged in secreting material for the formation of cells, it may happen that the conditions under which it is growing are so favourable that a superabundance of material for forming both leaf and root cells will be secreted. The plant will then develop abnormal outgrowths of leaf or root cells which it cannot retain permanently. Hence we find plants forming flowers, in which the stamens and petals are abnormal out-growths of leaf cells and the bulbous pistils are abnormal out-growths of root cells; or,

we find them developing, as in the case of some ferns, upon some of the normal leaves small abnormal bunches of leaves, which afterwards are detached and grow into perfect plants; or we find them developing masses of root cells, in the form of tubers or bulbs. If, when flowers are developed above ground, masses of leaf cell detached from the stamens come in contact with masses of root cell developed in the pistil, or if, when tubers are formed under ground, masses of leaf cells come in contact with masses of root cells in the tubers, in either case, the nuclei of separate plants are formed, which rapidly develop into young plants, and cover themselves with a husk or skin. In the seed the young plant is provided with large leaves, or cotyledons, and a small root; in the tuber it is provided with a large bulbous root, and a small eye or leaf shoot; and thus the tuber is the counterpart of the seed. We may notice that the petals of flowers are generally brightly coloured so as to reflect light, and that the corolla is generally, if not trumpet-shaped, so shaped as to converge the rays of light and heat upon the ovary of the pistil. The inner portion of the petals, near the root of the stamens, is often made of a dark colour or with dark patches, to absorb light.

Since plants obtain, as a general rule, their supply of water and of salts from the earth, they must,

as a general rule, be fixed on one spot, so as to give their roots an opportunity of penetrating deeply into the earth; at the same time some vegetable forms are found which are endued with locomotive powers.

114. We may now pass from vegetable to animal forms, which, as their cells are unable to separate the carbon particles from carbonic acid gas and thus to elaborate starch or albumin, are compelled to obtain the supplies of albumin which they require for the formation of protoplasm either directly from the cells of vegetable forms or indirectly from the cells of other animals, which have obtained their own supply from vegetable forms. Hence the animal must be a much more complicated form than the vegetable; for it must not only be furnished with appliances for breaking up or piercing the hard walls of vegetable cells, and with secretions for dissolving or dividing up, with the aid of water, albuminous and other compounds, to a sufficient extent to enable these compounds to pass into its cells or into its circulation, but since while the vegetable or animal matter is being dissolved, or put into a shape in which it will pass into the system of the animal, it must be retained in such a way that the useful portions of it will not escape, the animal must be provided also with a sac or stomach cavity, in which it may hold its food, and mix up its food

with water: it must further be provided with means of locomotion, to enable it from time to time to change its position to places where supplies of animal and vegetable food, as well as of water, can be obtained, or to enable it to avoid enemies, or escape from dangerous situations. And besides being furnished with a stomach sac and limbs, it is absolutely necessary, if the animal is to live and grow, that it should be furnished also with senses, to discern from a distance the obstacles, the situations, and the vegetable or animal forms which will injure, and the situations and the animal or vegetable forms in or with which it will find nourishment and security.

Though space forbids an attempt to work out all the steps by which vegetable forms have been differentiated into animal forms, it does not seem difficult to understand in a general way how, when vegetable forms had been developed, it might have happened that when some plant had been injured by the wind, or by a blow from some falling tree or mass of rock, or in some other way, the spores or germ cells of other plants might have fallen into a pool of sap collected in the wound, and, finding in the sap all the material they required for further growth, might have rapidly increased and formed masses of cells, which, as all their food would be derived from the sap of the wounded plant, and

would come from one direction, would naturally develop in the middle a pipe or cavity, by which the sap would pass to all alike. When such a mass of cells, arranged about a central cavity, had been formed, an alternation of expansions and contractions in the outside of the mass would set up a sucking action, under which the sap would continue to flow from the wound. Limbs would branch out from the sucking body, in the same way as roots and branches from a tree; and these, twining round the wounded plant, under the action of light in causing the unilluminated to grow faster than the illuminated side would, when they suffered contraction, force the mouth of the cavity tightly into the wound, causing the walls of the cells at the mouth of the cavity to grow dense under the great amount of contraction they suffered, and in time to become sufficiently hard to be forced by the contraction of the limbs deep into the tissue of the plant, and there being contracted by pressure from the sides of the wound, the mouth would remain small, while the outer part of the cavity was continually increasing under the greater amount of expansion it would receive. In course of time the cavity would become so much enlarged that it would be sufficiently capacious to hold a supply of sap which would last the parasite for some time, and the mouth would become so much contracted

that it would only open when the exhaustion was considerable; then the minute contractions and expansions under light and heat, in the body and limbs, would force the fluid in the cavity to circulate throughout the body and limbs; and at each contraction a portion of the fluid would escape through the outer cells of the body and through the anus—which would naturally form; consequently, after the cavity had been filled at each successive contraction the body suffered, the amount of contraction would increase, until at last the amount of contraction effected would be so great that the exhaustion produced by the subsequent expansion would be sufficient to open the mouth and pour a fresh supply of sap into the cavity. The parasite would now have a stomach sac, with mouth and anus complete, but unless endued with the power of locomotion would perish after it had sucked the plant on which it had fixed dry. Its young, however, if developed after the plant type, with stomach sacs, mouths, and root-like limbs, like the parent form, would, if detached and washed down by heavy rain into some estuary charged with floating masses of bruised vegetable matter carried down by torrents from the hills, be brought in contact with plenty of suitable food, which would pass into their stomach sacs as they expanded.

115. Now if the animal were in the form of a

plant, i.e. with extended limbs at both extremities (root limbs at one end, and branch limbs at the other) of a trunk or stem; and if the extremities of the limbs at both ends were so modified that they could entangle or attach themselves to any substances contiguous to them, in such a way as to be able to transfer all the force which reached them to those substances; and if then this animal were subjected to a series of alternating expansions and contractions,—it is clear that it would be able to move either backwards or forwards or even sideways if, at the end of each expansion, the limb or limbs in front, or in the direction in which the animal wished to move, should make themselves fast to some object so that the next contraction must carry the animal forward bodily in the direction of the object to which the limb in front was attached; and if after every contraction the limb behind were to make itself fast to some object, so that the next expansion would thrust the animal bodily away from the object to which the hind limb was attached, and therefore towards the object to which the front limb was attached, or in the same direction as the animal was carried by the contraction, it is clear also that by each contraction and by each expansion which it experienced the animal would ·e carried, little by little, in the direction in which required to travel. All therefore that is abso-

lutely necessary for locomotion is, that the animal should experience a series of contractions and expansions, and that it should be furnished with limbs before and behind, by which it might lay hold, alternately, of objects before and behind. But if an animal were dependent wholly for motion upon the amount of contraction and expansion which light and heat respectively would set up in it, it would plainly get along very slowly; and we may now therefore try to see how the contractions and expansions set up in the body by light and heat can be supplemented. If then the body or trunk of the animal is furnished with jointed limbs, capable of being drawn in or extended by the contraction or expansion of masses of muscle, made up of cells, with walls of some albuminous compound which contracts readily under the action of compulsive force, disposed so as to form a series of striæ or transverse layers for the whole length of the muscle; and if between these bands or striæ a series of arteries and veins are disposed in such a way as to bring up, periodically, supplies of fluid, in the shape of blood containing oxygen gas particles side by side with groups containing carbon and other particles, and to carry off waste fluid; and if a conductor similar to the wire of a battery, radiating at one extremity into an enormous number of branches whose ends are in connexion with every

portion of the surface of the limb, is in connexion at the other end with a condenser much of the same sort as the Leyden jar or other condensers used for storing up electrical currents; and if this condenser is connected by another conductor whose ends radiate into a large number of branches, with every point of the arteries and of the transverse layers of cells in the muscles,—it is clear that the condenser will receive by the conductor connected with the surface of the limb a charge of compulsive force every time the surface of the limb is contracted by compulsive force in the shape of waves of light impinging upon it, and will receive a charge of repulsive force every time the limb is expanded by repulsive force in the shape of waves of heat impinging upon it; and the charges of repulsive will discharge the charge of compulsive rce. But if the charges of compulsive force come
it is also clear that when the condenser has
charged with compulsive force the charge will
available for employment for the moment which
before the arrival of the next charge of re-
force; and therefore, since waves of light
at are constantly reaching the body, and are
ately contracting and expanding it, it is fur-
lear that charges of compulsive force will be
tically always available for employment. If
by a force impulse of some other kind, as by a

blow or a sound, or a visual impression, or in some other way, a charge of repulsive force is accumulated in another condenser, or in another insulated plate of the same condenser, having another branch of the same artery which supplies blood fluid to the muscles connected with it,—it is clear that then it will be possible, if the necessary connexions can be made, to discharge one of the charges of compulsive force in the first condenser by the conductor in connexion with the muscle, and through the artery in connexion with the second condenser, by means of the charge of repulsive force in the second condenser, in place of allowing the charge of compulsive force to be neutralized by the next charge of repulsive force in the ordinary way. It will then be the turn of the repulsive force charges to come first, and therefore thenceforward charges of repulsive force will be available for employment in the first condenser. The effect of sending a spark of compulsive force through the conductor and into the artery will be to set up the combustion of the carbon particles in the carbon compounds contained in the artery, at the expense of the oxygen particles, just as the same spark in an electric current is able to start the combustion of the carbon compounds contained in a jet of coal gas in the presence of oxygen contained in the air. And just as a very small spark or flame may cause a very big fire, so

too, may it be possible that the amount of carbon consumed in the artery will be limited only by the amount of oxygen present at the time in the artery, without any reference to the quantity or intensity of the discharge of force by which the combustion was set up. The combustion of carbon, as we know, develops light and heat, or compulsive and repulsive force; and if the compulsive force thus developed is conducted to the transverse layers of cells in the muscle it plainly will cause them to draw together, thereby displacing laterally repulsive force from the tissue between the layers of cells, and causing a thickening and shortening of the muscle and the drawing up of the limb. If then one of the charges of repulsive force which, owing to their taking precedence, will be now available in the first condenser, is employed to send a current in the reverse direction into the muscle thus contracted by compulsive force, we can imagine that it may be possible, either by repulsive force obtained [illegible] combustion of more carbon particles, or by [illegible]tion of the repulsive force displaced in [illegible] the limb, to conduct repulsive force to [illegible], and once more extend it.

[illegible] brain with its lobes, enclosed in the skull or [illegible], and insulated from the body by the neck, [illegible] the condensers [illegible] required; the sensor and nerves of the body—the one by its numero[illegible]

branches in connexion with the whole surface of the body, the other set by its ramifications in connexion with each set of muscles and with all the arteries—provide the two conductors required; the voluntary muscles, or muscles by which movements are communicated to the limbs and other parts of the body by the action of the will, are striated very much in the manner described (Carpenter's "Human Physiology, p. 783). Hence we may assume that in some such way as described animals are enabled to contract or extend their limbs, the contraction always preceding the expansion. Dr. Carpenter has pointed out that the facts that blood which returns from a muscle at rest resembles arterial blood in colour, while that which returns from a muscle in action resembles venous blood in colour, also that the quantity of carbonic acid exhaled bears a constant relation to the amount of muscular exertion put forth, show that the motor force employed in the contraction of muscles is generated by the oxygenation of the component elements of the muscle, or of those of blood (Carpenter's "Human Physiology," p. 13).

An animal provided with limbs which can be contracted and extended, and which are furnished with prehensile fingers or claws, can move itself easily, either by first raising and extending one limb in the direction in which it wishes to move, and then,

after clutching some object with the extended limb, contracting the extended limb so as to draw the body up to the object clutched, or by clutching some object in the opposite direction to that in which it wishes to move, and then extending the limb which clutches the object so as to thrust the body forward, or away from the object clutched. In both of these ways animal locomotion generally takes place—the limbs behind thrusting, the limbs in front drawing, the body forward. In the case of flying animals, the fore limbs are modified so as to produce wings able to clutch large masses of air; or in the case of fish, fins are provided, and the tail is modified so as to enable large masses of water to be clutched by the fins or lashed with the tail. An animal thus utilizes both the compulsive and the repulsive force developed by the consumption of material within it, whereas a locomotive engine only utilizes repulsive force; an engine is jacketed with a wooden or other lining to keep in heat, whereas a man takes off his jacket when he is walking very fast in order that the surplus heat he is unable to utilize may escape.

116. In effecting the complete contraction of a limb the whole of the free oxygen in the blood in the arteries about the muscles is consumed; this is shown by the fact that though arterial blood contains a large quantity of free oxygen, and blood

coming from a muscle at rest contains nearly half as much as arterial blood does, blood coming from a muscle in action contains hardly any free oxygen (ibid., p. 262); hence, after a muscle has once been contracted completely it cannot be contracted a second time until a fresh supply of blood has been received, or a fresh supply of oxygen has passed into the blood.

We may now, therefore, turn our attention to the circulation of the blood, by which fresh supplies of blood are furnished, and to the process of respiration, by which fresh supplies of oxygen are introduced into the blood. We have seen that animals of the higher types—by a lobed brain provided with two sets of nervous conductors, the one set, the sensor nerves, in connexion with every part of the surface of the body, the other set the motor nerves, in connexion with every one of the sets of muscles scattered over the body—are supplied each with a condenser or set of condensers, in which impulses of compulsive force or of repulsive force which reach the surface of the body and are conveyed to the brain by the sensor nerves are for a moment stored up, and can be discharged by means of the motor nerves through any of the sets of muscles with which the will connects them. We have now to see that in the heart, wrapped about as it is with bundles of muscle, nerve, arteries, and veins, and

having two sets of nerve conductors, the one from the cerebro-spinal the other from the sympathetic system (Carpenter, "Human Physiology," p. 274), animals are furnished with a coil, which acts as an accumulator in the way described in paragraph 98, to enable sparks to acquire sufficient head, so to speak, to leap across a break between the ends of the two conductors, which break may be assumed to be located in the cardiac plexus. If we suppose then that the ends of the two nerve conductors wrapped in a coil round the heart are so close to each other when the heart is contracted that currents are able to pass quite freely between them, but so far separated, owing to the tension of the fibres between them, when the heart is expanded that then sparks only can pass; and if we suppose also that the two conductors are connected with different condensers, one of the condensers being the one which we have already alluded to as being alternately charged and discharged by compulsive and repulsive force charges reaching it from the light and heat rays which fall upon the outside of the body through the sensor nerves, we shall be able to see that, when the heart is expanded, each time the condenser connected with the sensor nerves is charged with compulsive force from the sensor nerves, a charge will pass by a spark across the break between the conductors into the other

condenser, and whenever the condenser connected with the sensor nerves is discharged a spark will also pass across the break from the other condenser, but no spark will pass when the heart is contracted. Assuming that the lobes of the brain supply the necessary condensers, we may be able to get some idea of the heart's action; for since one part of the brain is being constantly charged and discharged by light and heat rays falling upon the body, it is clear that immediately the heart is expanded a spark will pass; the passage of the spark will set up the combustion of the carbon particles of the carbon compounds in the small arteries of the heart at the expense of the oxygen particles, in the same way as the spark sets up combustion of the carbon particles in the small arteries of the other muscles.

We may assume that the combustion of the carbon particles develops compulsive force, and produces contraction of the muscles, accompanied with lateral displacement of repulsive force, in the same way as in the voluntary muscles. As soon as the whole of the oxygen in the arteries has been burnt out, the displaced repulsive force will cause the muscles once more to expand. After the heart has expanded and the arteries have thus received a fresh supply of blood charged with oxygen, a spark will again pass from the brain, and set up once more combustion of the carbon and oxygen particles in the

having two sets of nerve conduct ... , followed ...
the cerebro-spinal the other from ... movements ...
system (Carpenter, "Human Phy... involuntarily. It
animals are furnished with a coil ... ly contracted by
accumulator in the way described ... electricity in one
enable sparks to acquire sufficient ... tory (Carpenter's
to leap across a break betwe... that the muscles
two conductors, which break ... ween the striped
be located in the cardiac plex... 274). The heart,
then that the ends of the two ... in the shape of
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other when the heart is con... the blood, by the
are able to pass quite freely ... first through the
so far separated, owing to ... expansion and con-
fibres between them, when ... driven into it, and
that then sparks only can ... from the lungs to
also that the two condu... left ventricle, it
different condensers, ... left ventricle to
the one which w... through the
alternately char... system of valves.
and ... small arteries it
light ... whose walls consist
the ...); and passing
able ... the veins, which
... back to the

... a limb is
... have to be

charge of carbon compounds and free
much the same sort of charge, be it
gun receives—or rather, as the useful
charge which a gun receives—only the
with an oxygen compound and free
of the carbon compounds and free
the arteries receive), and then fired;
the gun only utilizes the repulsive force
by firing the charge, the muscle utilizes
compulsive and then the repulsive force
in firing its charge.

attempt has been already made, in para-
to explain the way in which it may be
that a parasite, provided with a stomach
mouth and appendages, was developed from
form. It is therefore not necessary to al-
to the stomach sac with which animals
hed, or to the way in which food is divided
it enters the stomach—by jaws armed with
engthened with cells with hard walls much as
ghs of a tree are strengthened, set in motion
opriate muscles worked in the same way as
muscles are worked—or to the way in which
od in the stomach, after being dissolved by
of water and various secretions elaborated
rtain cells, is imbibed into the body by roots
nd cells, and gradually changed from the
egetable cells to that of animal cells, and

mixing with the blood as white or red corpuscles, or in other ways is utilized to build up tissues, repair waste, supply force, &c.

Nor is it necessary to allude to the skeleton, or skin, or outer covering of the animal, further than to point out the general correspondence between the trunk, limbs, and bark of a tree and the trunk, limbs, and hide of the animal; but we may turn to the consideration of the senses with which, as we have seen, it is necessary an animal should be endowed.

118. It is plain that an animal furnished with sensor nerves, ramifying from the brain as a centre to every part of the surface of the body (see Haeckel's "Essays on Cellular Psychology," or Herbert Spencer's "Principles of Psychology," vol. i., p. 25), and conveying to the brain—which acts, as we have seen, as a condenser in storing up force—all force impulses which reach the surface of the body, will, if its brain is placed upon a neck, which serves as a stand to insulate it from the body, and above all from the ground, feel uncomfortable in any situation in which the compulsive force impulses reaching the surface of its body are much stronger or much weaker than the repulsive force impulses reaching it; for if either the pressure or the cold was excessive the animal would, having an excess of compulsive force stored in its brain, experience a sensation of heaviness, or inability to

extend its limbs; whilst, in a situation where either the heat was excessive or the pressure very small, it would experience a difficulty in contracting its limbs, and therefore in moving; hence the animal would be warned by its sensations against moving towards situations where the temperature or pressure was unsuited to animal life. It is also clear that the animal, besides being rendered uncomfortable by the surface of its body as a whole being exposed to conditions of pressure or temperature unfavourable to movement, would also be rendered uncomfortable, and might be hampered in its movements, if any parts of its body were to receive a severe blow or a wrench; for part of the force from the blow or the pull would be stored up in the brain; and if it were stored in the same condenser as that used in the movements of the limbs, would hamper the movements of the limbs until it was worked off; or, on the other hand, if it was stored in another condenser it would facilitate movement, as we have seen. If then the animal is furnished with long feelers, or tentacles, carrying sensor nerves in connexion with one of the lobes of the brain, and made very fine and very long so as to project far in advance of the body, it is clear that if, when it is moving, any large obstacle to its further progress lies in its path these feelers will, by striking against the obstacle and transmitting the

force of the blow to the brain, give the animal notice of the existence of the obstacle in time to enable it to stop before reaching the obstacle. And if now, instead of having a thin inside coating of solid metal, as the Leyden jar or electrical condenser has, the brain of the animal is made soft and massive, and consists largely of carbon compounds and water or other fluids, and is permeated everywhere with small arteries conveying blood, and other fluids containing oxygen, to enable fresh tissue to be built up, or the grouping of particles in old tissue to be modified, and furnished also with veins running side by side with the small arteries, and acting as waste pipes to remove surplus fluids and material—just in the same way that the muscles are furnished with supply pipes bringing blood and oxygen, and with waste pipes to remove surplus material—it is clear, since, as we have seen, force, if it is not transferred, always produces definite changes within a mass of matter to which it is communicated, that the force communicated to the brain by every blow which the ends of the feelers receive by impact against obstacles lying in the animal's path, will, if it is not at once transferred, induce definite changes in the animal's brain, causing a condensation of the particles about the root of the conductor or sensor nerve in the feeler, or an alteration in the grouping of the particles in the material of the brain, and

displacing force of the opposite kind, which can be utilized in the movements of the muscles of the limbs or other parts of the body in the manner already described. Thus, if in the animal's brain certain portions or lobes are set apart for the use, so to speak, of the feelers, a more or less permanent record will be left in its brain by every obstacle against which its feelers impinge. And if, further, the feelers are capable of being moved by sets of muscles in which movements of the same sort as those of other muscles can be set up, and if while the muscles of the feelers are in motion a portion of the force which, as we have seen, is displaced from the muscles is utilized to produce other changes in the grouping of particles in the material of the brain, the animal will be able to form in its brain an engraving, so to speak, of the surface of the obstacle opposite to it; for by bringing its feelers together to one portion of the surface, and then passing one of them upwards or downwards and sideways across the surface from one edge to another, the points where contact begins at one edge and ends at the opposite edge, and the amount of extension or contraction of the muscle necessary to move the feeler from the point where contact begins to that where it ends, will be engraved upon the brain by changes in its material, and thus a picture or, rather, an engraving, of the surface will

not only be obtained but retained in the brain; and this picture will be deep and permanent or shallow and transient, according as much or little time and attention, or force and material, are given to its execution. By subsequently transferring force of the opposite kind to that by which the picture was produced through the lobe of the brain on which it is engraved to the lobe of the other feeler, the picture will be effaced on the lobe or side on which it was first engraved, and engraved on the other side by the force displaced in effacing the picture, which will be, plainly, the same force exactly as that by which the picture was originally produced. And so long as the picture remains engraved upon the brain it can, by being transferred from one side to the other of the brain, be reproduced by this process of recollection or memory, as we call it, as often as the animal wishes. Thus, as the animal moves along it will be able to store up in its brain pictures of all the obstacles it encounters; and if, instead of moving heedlessly along between the different sets of obstacles it encounters, it utilizes a portion of the force displaced in the muscles by every movement to produce a record in its brain by means of the changes induced by the displaced force in the grouping of particles in the material of its brain, it will then have a complete record of the path, showing not only the obstacles in the way, but also the

number of times the limbs must be moved in passing from one obstacle to another. As the animal grows older, picture upon picture will be stored in the different layers of its brain; and though some of those pictures which were lightly graven will wear out or be effaced by others, those to which much attention was given, and which, being often gone over and revised by comparison with the original, are deeply and firmly cut, will remain all through its life. A set of brain pictures of this sort constitutes, as it is called, a stock of Experience, upon which, by the process of Recollection already explained, the animal can draw at any time for guidance.

119. The pictures of obstacle thus engraved upon the animal's brain by the means of feelers are engraved by force developed in the body of the animal, or rather by force displaced from the obstacle with which the feeler comes in contact by force developed in the body of the animal and transferred to the obstacle by the feeler, the attention of the animal being engrossed or confined by the very form of the feeler to the object or objects with which at the time the feeler is in contact. But since solids transfer force to the particles of gaseous masses with which they are in contact, and the particles of the gaseous masses in their turn, as we have seen at paragraph 49, transfer the force they have thus received

to other solid masses, it is clear that if any mass of matter is transferring a large amount of force to the particles of air surrounding it, force transferred by the air will reach the body of an animal approaching that mass before the animal's body or feelers come in contact with the mass, and that in this way, without the aid of feelers, an animal may be made aware of the existence of obstacles, if the obstacles are able to transfer force in large amounts to the air; though at the same time, since the force thus transferred through the air would act upon the whole surface of the animal's body opposite to the mass, it is clear that no precise information in regard to the form and extent of the obstacle could be obtained. If, however, a small portion, in the form of an eyeball, of the animal's body were separated from the rest, and, though connected by a conductor with the brain, otherwise insulated, so as to be unable to transfer force readily to any other part of the body; and if at the same time this ball were so enclosed or shut off from the brain and the rest of the body, as well as from the outside, in a socket or depression in the surface of the body, that no force could reach it except the force transferred by an object directly in its front,—it is plain that the eyeball, if it were composed of some stable compound in which the grouping of the particles could not be readily altered by any force likely to reach the ball, would contract

or expand under impulses of force which it could not transfer to the body and which were not sufficiently great to induce alterations in the grouping of its particles nor to produce movement involving change of position in the ball; and if the interior of such an eyeball were filled with some fluid which would expand and contract under the action of force more readily than the outer portion of the ball contracted or expanded,—the eyeball would, it is plain, being prevented by the socket in which it was enclosed from drawing nearer to the brain when its fluid contents contracted, exert a pulling strain upon the brain by tending to shorten the length of the conductor connecting it with the brain. We shall perhaps be able to understand better the dragging action which an eyeball of this sort, when it contracts, will exert upon the brain, if we consider the effect exercised by contractions in the mercury in a thermometer upon the top of the glass tube of the thermometer. For the bulb of a thermometer, filled as it is with a fluid which expands and contracts under the action of force more readily than the glass bulb, and having attached to it a stalk in the form of a tube, may plainly not inaptly be compared to an eyeball with a conducting stalk of the sort explained. We can show experimentally that a column of mercury in a tube forms a piston, or rather a plunger, and that a

piston if it is forced up towards the closed end of a tube produces pressure upon the closed end, or if it is drawn back away from the closed end exerts a pulling strain upon the closed end; and we may see the mercury column, when the mercury in the ball of the thermometer contracts, shortening and drawing away from the closed end of the tube, and therefore putting a pulling strain upon the closed end of the tube; and so also plainly must an eyeball in a socket produce a pulling strain upon the brain of an animal, if the fluid contents of the eyeball contract more readily than the outer portion of the ball. The analogy between the case of the eyeball and that of the bulb of the thermometer will be seen to be more complete if, for the same reason that the bulb is made of a transparent material allowing rays of heat and light to pass through to the mercury inside, the eyeball also on the one side from which force reaches it is made with a transparent covering which allows rays of heat and light to pass through to the fluid contents of the eyeball.

We have seen that when the eyeball contracts it exerts a pulling strain upon the brain, owing to the socket preventing the shortening of the nerve or conductor connecting the eyeball and brain. We may now remark that the socket will not prevent the extension of the nerve or conductor; and that if there is nothing to prevent this except a few muscles,

which themselves are liable to be extended by any force which tends to expand the eyeball and extend the nerve, the brain, although it will be stimulated by the action of compulsive force entering the eye in the form of rays of light, will not be stimulated, or at all events will not be stimulated to the same extent, by the action of repulsive force entering the eye in the form of heat. And therefore the eyeball differs from the thermometer in indicating the action of light rays instead of that of heat rays. Now animals are furnished generally each with two eyeballs, filled with fluid, and pierced on one side with a hole or pupil, with a transparent covering, or cornea, through which rays can enter and reach the fluid contents of the eyeball; and these two eyeballs are connected each by an optic nerve with the brain, and at the same time are placed in sockets which prevent the shortening of the optic nerve, and are held in position in the sockets by muscles capable of expansion under the action of heat. Hence it is clear that animals so furnished will be able to recognize, by the dragging effect exerted upon the brain, the presence of objects which radiate compulsive force in the form of light to their eyes, and thus produce contraction in the fluid contents of the eye. It is also clear that an animal furnished with two eyes, capable of being moved in the same way that feelers are moved, can, by directing the eyes to any

object radiating compulsive force, and moving the eyes, obtain a picture on its brain of the surface of the object, delineated by the changes in the grouping of the particles in its brain caused by the pulling action upon the brain exercised through the eye by the compulsive force from the object, and to force displaced from the muscles in the act of moving the eye. Such a picture will be similar to the picture formed upon the brain by the medium of feelers, but will differ in this one respect, that whereas the picture obtained by means of the feelers is engraved upon the brain by pressure, that obtained through the medium of the eyes is embossed or executed in relief by tension. The brain may be stored with pictures obtained through the eye in series upon series in its different layers, just as it may be stored with pictures obtained through its feelers; but in order to institute a comparison between the picture of an object obtained through the eye with that of the same object obtained through its feelers, it must first reverse the picture obtained through the eye. Pictures can be obtained through the feelers at any time in light or darkness, but those obtained through the eye can only be obtained when the object is illuminated; hence pictures obtained through the feelers will naturally supply the standard to which other pictures will be referred. Though animals are furnished with two

eyes, one eye only is apparently concerned directly in the production of the picture in the brain, and the other eye simply transfers the force it receives so as to supplement the force at work in the other eye, and thus produce one picture only. We can see this by moving so as to bring two objects into line when looking at them with both eyes, and then, when the two objects are in line, closing first one eye and then the other; for we shall find that the objects remain still in line when one particular eye is closed, but are no longer in line when the other eye is closed, showing that a different picture of the two objects is then obtained. We are accustomed to recognize this by speaking of one eye as being stronger than the other. On the other hand, we can show that both eyes are actually employed in the formation of the picture, though one merely assists the other, for if while we are looking at any object we apply the finger to one eye so as to force it slightly down, we shall then obtain two pictures of the object.

But though with the lower animals representations of objects may be roughly executed on the brain in the manner described, in the case of the higher animals, the representations of objects will be far more carefully and faithfully executed. For if we take the case of our own brains we find that our arms and hands supply the place of the antennæ or feelers of other animals of lower types, and that our feelers

branch out at their extremities into fingers with sensitive tips; also that with these branched fingers we can, by the sense of touch, obtain very complete representations of those portions of the surface of any object which may at the time be opposite to us. We find also that just as we are provided with branched feelers, so also the extremity of the optic nerve in our eyes is branched in such a way as to spread out over the whole of the retina, or portion of the eye upon which the rays of light, when they have entered the eye and passed through the transparent fluid which it contains, fall, and thus furnish us with a very complete representation of those portions of the surface of any object which may be opposite to us.

120. In the human eye the adjustments are very complicated, and we may perhaps for a time profitably turn our attention to them. We may notice then, in the first place, that the whole of the eye, except the portion in front covered by the transparent cornea, is enveloped in the opaque white sclerotic membrane, which reflects all light and excludes it from entering the eye anywhere except through the cornea. We may notice next that the greater part of the light which passes through the cornea is cut off and absorbed by a dark-coloured membrane called the iris, which is stretched behind the cornea, and allows only a comparatively small portion of light to pass

to the optic nerve and retina through the pupil, or small hole which is pierced in the iris, and which contracts in strong light and expands in dim light thus regulating the amount of light which enters the eye, and plainly following the contractions which the eyeball itself undergoes under strong light. The light rays which pass through the pupil fall upon the crystalline lens, by which, in the manner described in paragraph 105, they are bent or refracted, in the same way as rays of light are refracted by the lens in a photographer's camera, and focussed upon the retina of the eye. The crystalline lens is a double convex one, and according to Helmholtz ("Popular Scientific Lectures," p. 205) becomes more convex, especially on the outside, by the contraction of the ciliary muscle, when the eye is looking at near objects than when it is looking at distant ones; in this way, when at rest being adjusted to see distant objects distinctly, the eye accommodates itself to look at near objects. Since near objects send much more light to the eye than distant ones do, they naturally produce more contraction in the eyeball than distant ones; and here again, as in the case of the pupil, we see light directly producing contraction. It seems important to notice that while the sclerotic membrane is made white so as to reflect light, the iris, which, as well as the ciliary attachment behind it, is required to

contract under strong light, is made dark-coloured so as to absorb light. The choroid membrane outside the retina is also made dark-coloured, so as to absorb all light rays which enter the eye.

If we bring the eye close to, i.e. within an inch of, a fine bright metallic point, or a very minute hole in some opaque substance, so as to allow rays of strong light to pass from the point, or through the hole, into the eye, we shall notice on the

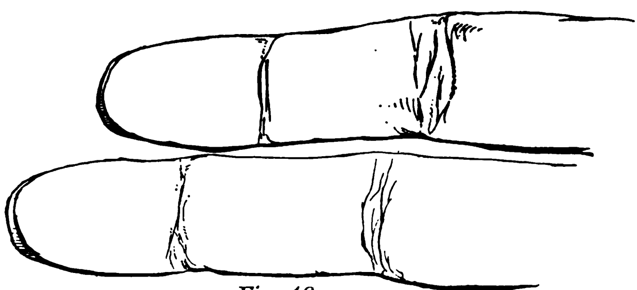

Fig. 10.

point or in the hole a brilliant spot of light, consisting of a series of concentric rings, alternately bright and dark, of which the outer ring is a bright one.

The concentric bright and dark rings in these spots seem in some way connected with the arrangement of the particles of which air is composed about the point or in the hole on or in which the spots of light are seen. We have already seen, in paragraph

24, that solids condense films of air particles upon their surfaces, and if we take any solid (one finger of the hand will serve well for this purpose) and hold it up against the light, within about two inches of the eye, we shall notice that the outline of the surface is not sharp and distinct, but that, clear of the surface, a dim, hazy, dark-coloured film stretches all round it for a depth of perhaps about one-twentieth of an inch; if we then bring another finger near to the one at which we are looking, so that the one may nearly touch the other, in the way shown in Fig. 10, we shall see, by looking between the two fingers, that, as one finger gets near the other, the hazy films about the approaching surfaces meet when the fingers are as close to each other as in Fig. 10, and a dark band marks the junction of the films. If the fingers are brought still closer together other dark bands appear, which, when the fingers get still nearer together, though before they are actually touching, coalesce, and form dark patches of the same pink colour as the hand at the joints, where, owing to the prominences, the surfaces are closer together than elsewhere; finally, when the fingers touch the alternating bright and dark bands merge here and there at points, where light still finds its way through, into the spots with concentric rings, alternately bright and dark, seen in minute holes or upon fine points. If the fingers are slightly wetted before the hand is

held up, the same patches will be formed with water instead of with air.

If, while we are looking at one of the spots of light in a minute hole in some opaque substance, we pass a card or some other flat opaque body slowly between the eye and the hole, so as gradually to cut off the rays of light which pass through the hole from entering the eye, we shall find that if the card is passed across from above downwards the bottom portion of the spot of light is first obscured, and the top portion the last to be obscured; whilst if the card is passed from below upwards the top portion is the first and the bottom portion the last to be obscured; or if the card is passed across sideways from left to right, then the right side of the spot is the first and the left side the last to be obscured; or if the card is passed from right to left, then the left side of the spot is the first and the right side of the spot the last to be obscured. Thus the shadow of the card always moves across the spot in the opposite direction to that in which the card is moving, or in the reverse direction to that in which a shadow ordinarily moves, clearly showing that the image of the spot is reversed in the eye.

Again, if while looking steadily at one of these spots of light in a minute hole or on a fine point the eye is gradually closed, we shall find that the pot is gradually reduced from a perfect disc to a

narrow horizontal streak, consisting of a series of bands alternately bright and dark, intersected by a number of dark spaces due to the shadows thrown by the eyelashes (which shadows, it may be noticed, will be seen in strong light to be made up each of a series of fine bands, alternately dark and bright), and finally the spots will be entirely obliterated when the eye is quite closed. If, however, after the eye has been so far closed as to convert the spot of light from a disc into a streak, the lids are kept for some time in the same position, thus nearly closing the eye, and the streak of light thus obtained is steadfastly contemplated all the time, and then the eye is suddenly opened to the full extent so as to see once more the spot as a perfect disc, a persistent image of the streak with its bright and dark bands will be seen right across the disc for several seconds, though gradually getting fainter and fading away. The persistence of the bright and dark horizontal bands of the streak across the circular bright and dark rings of the spot, seems to show that the bright and dark bands in the streak represent a series of alternating ridges and furrows, either in the retina of the eye or on the surface of the brain, and not merely a series of illuminated and unilluminated spaces. It would almost seem that these persistent horizontal bands are due to the motion of the eyelid, since they begin to appear at once

directly the lids begin to more, whereas they do not appear to be formed when a spot of light is converted from a disc into a streak by the passage of a card or other flat opaque substance between the eye and the hole or point on or in which the spot is formed, also the bands are even more distinct in a dim than in a very strong light. We have thus, perhaps, here, an illustration of the way in which images of objects are obtained by the changes produced in the grouping of particles in the brain by the combined action of force acting through feelers or eyes, and that displaced from muscles attached to the feelers or to the eyes.

The fact that these spots of light are reduced from the form of a disc to that of a semicircle or of a segment of a circle, and finally to that of a streak, when the eye is partially closed by the drooping of the upper eyelid, shows that the size and form of the spots depend upon the size and form of the upil of the eye. This is further shown by the fact hat if several fine bright points, or several exceedingly minute holes close together, are examined in ace of a single point or a single hole, a number of ots corresponding to the number of the points or les will be seen, in place of the single spot seen ith a single point or hole; and when a number of spots are seen together it is to be noticed that all are of exactly the same size one as another. This

also is shown by the additional fact, that under a dim light, when the size of the pupil, as we have seen in the preceding paragraph, is large, the spots are larger than they are under a strong light, when, as we know, the size of the pupil is reduced.

If, keeping in remembrance the general appearance of the spots of light, with their concentric rings, alternately bright and dark, and with the outermost ring a bright one, and with their reversed images, we now go into a dark room, and apply pressure, by the tip of the finger or by any pointed substance, to the portion of the ball of one of our eyes lying between the pupil and the nose, a spot of light, known as a phosphene, consisting of a number of more or less concentric rings, alternately bright and dark, of which the outermost ring is a bright one, will make its appearance on the opposite side of the eye to that at which the pressure is applied. If we shift the point of application of the pressure the spot will shift too, keeping always on the opposite side of the eye to that at which the pressure is applied; thus, if pressure is applied above the pupil, the spot will appear below the pupil; if the pressure is applied below the pupil, the spot will appear above; or if it is applied on the left side of the pupil the spot will appear on the right side, and so on. If pressure is applied to the eyeball when the eye is in strong light, a dark spot, apparently produced by

the nerves of the eye being fatigued, in the same way that they are fatigued with the result of inducing temporary blindness under the action of excessively strong light, is seen in the same relative position as the bright spot is seen when pressure is applied to the eyeball in a dark room.

In the fact that the general appearance produced, both when rays of light pass from a pointed substance, or through a hole made by that pointed substance, into the eye, in such a way that their action is not interfered with by other rays, and when force is transferred from a pointed substance to the outside of the eye, is that of a spot of light made up of concentric rings, alternately bright and dark, of which the outermost ring is a bright one, and having its image reversed, we have evidence in regard to the action of light which seems irresistibly strong, and the more so if it is noticed that the application of pressure to the eye produces no effect if it is applied over the pupil, or unless it is applied over the portion of the eye lined by the retina, or in other words to the same portion of the eye as that on which rays of light act. For if, setting aside minor differences, the effect produced by the transfer of force in the form of light from a pointed substance to the inside to the eye is the same as that produced by force transferred from a pointed sub-

stance by pressure to the outside of the eye, it is clear that the action of light on the inside is that of a dragging force tending to draw in the portion of the retina on which it acts, since the tendency of pressure applied to the outside is to drive in the portion of the retina upon which it acts, and thus produce condensation by the action of displaced compulsive force, as we have seen at paragraph 33.

121. The eye is clearly the most important of all the organs of sense connected with what may be called the intelligence department. The ear is another organ connected with the same department, though a less delicate one than the eye; for whereas the eye is very readily excited to action by any development of compulsive force in the form of light, the ear is only excited by force received by motion and impact (see paragraph 49), or in other words, by the blows struck upon it by masses of air set in motion by impulses of force, which they are unable to transfer without change of position. The ear is made in the form of a thin membrane, which, moving readily under the action of force, transfers force received by the impact of a mass of air in a motion against it, by a blow or a succession of blows to the brain. The membrane of the ear is placed in depression in the surface of the body, and otherwise fenced round, so that impulses of force may reach it

from one direction only, and thus animals may know the direction from which the sounds or blows which excite the ear come. The force which the brain receives by blows from the ear, when not utilized in setting up motion in the muscles of the limbs or other parts of the body, produces changes in the grouping of particles, which are duly registered or stored up in the brain in the form of sound pictures, representing the strength and frequency of the blows, but not the size or conformation of the surface from which the blows were received. The animal being furnished with two ears can transfer sound pictures across from one side of the brain to the other, and thus reproduce sound pictures by memory, in the same way that it reproduces pictures produced by touch or sight.

122. The sensations of taste and smell, though due, like other sensations, to force, differ from those of feeling, seeing, or hearing, since they seem to be due to force developed in the tissues of the body by changes of chemical combination in the particles of which the tissues are made up, induced by contact with the particles of the masses of matter tasted or smelt. This is very clearly indicated by the fact that oxygen gas, which in the ordinary form is an inodorous gas, becomes odorous when condensed into ozone, and also becomes exceedingly active, so that it acts strongly upon organic substances, on

which in the form of oxygen it has no action (see paragraph 66).

By the sensations of taste and smell an animal is enabled to discriminate between the different kinds of food available for use, or to tell whether gases unfavourable to existence are present in the air about it.

The force developed by the changes of grouping in the particles of the tissues connected immediately with the organs by which the sensations of taste and smell are produced, being transferred to the brain by the nerves of taste and smell may be conceived to induce changes in the grouping of the particles of the brain at the root of the nerves, in the same way as changes of the grouping of particles of the brain are induced by force reaching the brain by the other sensor nerves, and thus a series of taste or scent pictures are stored up in the brain.

Since the animal is furnished with two nostrils, scent pictures can be reproduced by memory at any time.

The membrane in which the changes are induced by which the force producing the sensation of smell is developed, is placed in a depression and otherwise fenced round, in much the same way as the membranes connected with the sensations of sight and hearing are placed in depressions and fenced round, so that gases by whose presence the changes

producing the sensation of smell are set up may reach the nostrils from one direction only, and thus the animal may be informed of the quarter from which the gases come.

123. An animal endued with the power of locomotion, and with a stomach or sac in which a supply of food to furnish fuel for locomotion and material for growth can be stored; furnished also with the necessary appliances for collecting and storing food in a proper condition for use, and with senses to enable it to select the kind of food which it requires; furnished also with senses to enable it to discern from a distance, whether by night or day, the position and characteristics of animals, or vegetables, or inanimate masses of matter around it; furnished also in its brain with a store of pictures representing the characteristics of other animals, vegetables, or inanimate masses of matter it has before met with, and able to institute comparisons by the operation of memory between the pictures representing the characteristics of friends and foes and of situations and things beneficial or noxious which it has before met with, with those of the beings or things at the time present before it, and thus to discern whether it is in the neighbourhood of beings friendly or hostile to it, or in that of things or situations noxious or beneficial,—is able to look after itself, having a fund of experience, or, in other words, a

stock of brain pictures, on which to rely for guidance in any emergency. But if animals require to be so well furnished before they are able to do for themselves, it is plain that if they are developed from a simple cell or group of cells, as plants, as we have seen, are, they would be in a bad way if turned adrift as simple spores or seeds to do for themselves; hence we find with animals that the young, even when they are separated from the parent in the egg form, are provided with a stock of food in the shape of yolk globules, on which they can subsist, and that the eggs are not scattered at random, as the seeds of vegetables are, but are carefully placed in some situation where heat and moisture will reach them, and are sometimes, as in the case of birds, placed in a nest and supplied with warmth and moisture by contact with the body of the parent by the process of incubation, and are when hatched from the egg generally fed and cared for until they have acquired strength and experience to do for themselves. In the case of others of the higher animals whose young do not separate from the parent in the egg form, the young remain attached to the parent until, in many cases, they are perfectly developed, and when they separate are fed by fluid secreted by the parent, and cared for until they have acquired sufficient strength and experience to do for themselves. The young animal may be as-

sisted in acquiring the necessary experience, or in stocking its brain with pictures, by warnings communicated through the eye or ear by the parent; or it may perhaps in some cases acquire hereditarily the necessary layers in its brain to enable it to perform the functions devolving upon it, by instinct as we are accustomed to call it.

We have seen, in paragraph 113, that plant cells naturally differentiate into cells of two kinds, one kind fitting themselves to inhale gases, strain out carbon from carbonic acid, and elaborate starch, and taking the form of leaf cells; the other kind fitting themselves to imbibe the moisture and salts from the earth required for the proper growth of the plant, and taking the form of root cells. We have seen also how when the plant is in full vigour, at certain seasons when the conditions under which the plant is growing are specially favourable to the secretion of cell-forming material, it may happen that a superabundance of cell-forming material may be secreted, and that then abnormal outgrowths, which cannot be permanently retained, of leaves in the form of young plants or in the form of flowers with petals and stamens, or of roots in the form of tubers or bulbs, or in the form of pistils with ovaries will occur; and how that if a mass of leaf cells from the stamens should come in contact with a mass of root cells in the ovary of a pistil the conjugation of the

two masses will give rise to a new mass containing both root cells able to imbibe moisture and salts and leaf cells able to inhale gases and elaborate starch, and therefore perfectly fitted to develope into a plant; and that accordingly the mass of conjugated root and leaf cells will, under favourable circumstances, quickly develop into a young plant, and covering itself with a husk take the form of a seed. We shall not, therefore, have much difficulty in understanding how animals too, when in full vigour, may at certain seasons, when the conditions are specially favourable to growth, secrete a superabundance of cell-forming material; and how abnormal outgrowths which cannot permanently be retained will then be developed by them. But inasmuch as the animal obtains, as we have seen, all its supply of food and moisture from its stomach and lungs, or by root cells, and requires only from its outer cells a supply of force to enable it to initiate the changes on which the movements of its muscles depend and to supply it with intelligence, and its cells, instead of differentiating into root and leaf cells as do those of plants, differentiate into root cells and nerve cells; when then a superabundance of cell-forming material is secreted by the animal, the consequent abnormal outgrowths will take the shape of nerve cell material in the form of spermatozoa corresponding to the leaf cell

masses of pollen produced by the plant, or that of root cell material in the shape of ova corresponding to the ova in the ovaries of the pistils in the plant, or in the shape of buds by gemmation as in the case of the protozoa, or in the shape of young animals by parthenogenesis in the metazoa (Balfour's "Embryology," pp. 5—12). And if one of these spermatozoa or masses of nerve cell material should come in contact with an ovum or mass of root cell material it is plain that the conjugation of the two masses will give rise to a single mass containing the two kinds of cells required for the development of a perfect animal; and accordingly it is found that if the conjugation of the two masses should take place under favourable circumstances the development of cells of the two kinds called respectively epiblast and hypoblast cells will at once commence, by the process of segmentation or division of the mass, first into two parts, then into four, then into eight, then into sixteen, then into thirty-two, then into sixty-four, and so on, parts, which first arrange themselves in the form of a blastosphere or spherical shell about a segmentation cavity; and then, when the blastosphere has been formed, the hypoblast separate from the epiblast cells, either by one-half of the blastosphere bulging inwards and forming a two-layered hemisphere, with the hypoblast layer inside and the epiblast layer outside, or by the

blastosphere splitting into two layers, the inside layer being the hypoblast one. The epiblast layer subsequently develops a cuticle and nervous system; the hypoblast develops the digestive and secretory organs (Balfour's "Embryology," pp. 75 and 103). Finally, with the addition of mesoblast cells, differentiated partly from the epiblast and partly from the hypoblast cells, the complete animal is developed. In the lower animals, in some cases, both spermatozoa and ova are developed by the same individual, just as stamens and pistils are in most cases developed on the same plant. But in the higher animals, spermatozoa or nerve cell masses are developed by the male, and ova or root cell masses by the female; just as with some plants stamens alone are developed by some plants and pistils by others.

124. We have seen, in paragraph 110, the extreme importance to an animal or plant of the colour of the different parts of its body, leaves, or flowers, since the colour determines the quantity and kind of force admitted to or reflected from the coloured part in the shape of light and heat. We may notice then how very generally dark bands or patches are found, often contrasted with light ones, on parts where great muscular activity prevails. Thus the fore part of the front and hind legs of animals is usually dark coloured, or darker than the

rest of the body; so also dark-coloured necks and muzzles and dark patches about the eyes and along the back are often found; also dark-coloured bands and patches are often found on the wings of birds or butterflies. The eye-spots on caterpillars, such as Chærochampa Elpenor (the Elephant Hawk Moth), over the place where the future wings are to come, seem also specially deserving of notice.

CHAPTER VII.

CONCLUSION.

Let us hear the conclusion of the whole matter: Fear God and keep His commandments, for this is the whole duty of man. For God shall bring every work into judgment, with every secret thing, whether it be good or whether it be evil.—ECCLESIASTES xii. 13, 14.

125. PERHAPS it may have seemed to some that we have drifted away altogether into materialism and got clear of God. We have seen that life has a physical basis, that it consists essentially in the successive expansions and contractions set up by the action of heat and light in a cell or mass of matter consisting, on the outside, of certain albuminous compounds which contract readily under the action of compulsive force, on the inside, of a quantity of fluid. We have seen too that by the expansion of its walls a cell of this sort is made to drink in gases and fluids, which, when subsequently condensed by the contraction of the cell, enter into combination with some of the liquid or solid particles in the fluid inside the cell, and form material for the growth of the cell by the enlargement of the

cell walls, or for the growth or development of the body of which the cell forms a part by the formation of walls for other cells, or for the formation of a membrane or a hard coat to strengthen the outside of the cell walls; also, that by the subsequent contraction of its walls the interior of the cell is made to give up the material it has secreted, and that this as it passes drops into some vacant place in the walls, and, coming to rest, increases the size of the walls of the cell; or going further, lodges outside the cell and forms a membrane or hard sheath; or going still further, forms the nucleus of another cell; or going on, enters some other cell and furnishes it, after it has undergone further combination, with material for the elaboration of the more complex secretions which the animal requires for the processes of digestion, mastication or lubrication, or with material for forming the different kinds of sheaths which cells in different situations require to enable them to form bone and ligament, nerves and skin, or woody fibre, bark, and bulb. And thus the perfect animal or the perfect plant is built up, whether, as in the lowliest forms, it consists of a simple string or bundle of cells, or whether, as in the highest forms it possesses a trunk with roots and branches and leaves able to develop flowers and fruit, or a body with limbs and stomach heart and brain, able, like the tree, to reproduce its kind.

We have seen also that the formation of cells is due to the tendency to arrange themselves in groups in regular order which particles of every form and at every stage exhibit under the action of the two forces of compulsion and repulsion with which they are endued, and owing to which not only cells and animate bodies or aggregations of cells are formed, but also crystals and amorphous masses of matter, and inanimate heavenly bodies in the shape of sun, moon, and stars, which are aggregations of crystalline and amorphous masses, are built up and sustained. And hence at first sight it may appear that we have quite banished supernatural agency, and substituted for it a mechanical agency, and thus have struck off blindly into new paths where there are none of the old landmarks to guide us. But indeed it is not so; for though no doubt we have tried to explore new paths, the old well-known landmarks have been in sight throughout our journey, and they are in sight now at its close if we will but open our eyes to see them.

The proverb says that extremes meet. And what then is this compulsive force, with which every particle, and every mass, and every body animate or inanimate, is begirt, and being thus begirt is compelled to take its appointed place from time to time, in group, or cell, or crystal, or mass,

or body, in solid, in liquid, or gas, and to move into its place always in a perfectly orderly way —but a manifestation or an expression of the will or power of God, Omnipotent, Omnipresent? And what then is the repulsive force with which too every particle, every mass, and every body animate or inanimate, is begirt, and being thus begirt endeavours constantly to escape from the positions into which it is brought by compulsive force, in group or cell or crystal or mass or body, and thus to resist and undo and frustrate and mar the work of the controlling all-compelling power—but an expression of the power or will of the power or powers of evil constantly opposing and resisting the power of God or Good? There can be no mistaking this; here we are face to face again with the old Bible story of a conflict ceaselessly going on between the two powers of Good and Evil—the same story, too, which is at the base of all religions. Only the story is traceable here not merely in books or in pictures, but everywhere, in the densest solid mass or in the lightest vapour, in the tiniest atom and in the largest orb, written—or rather, modelled—on every one of the thousands of particles of which even the tiniest atom we can recognize is made up.

126. We thus bear about us in every fibre and cell in our bodies, repeated over and over and over again upon each one of the thousands upon thousands of particles of which each of those fibres and cells is

made up, a story of creation which is substantially the same as that we find in the Bible. Let us look at it then. The story repeated upon each particle shows, first, a world of disorder, a wild confusion of atoms each in the grasp only of repulsive force—an earth "without form," to use the words of the Bible; and then comes compulsive force or light, as the Bible says, upon the scene, and immediately particle joins particle to form groups, and group joins group to form masses, and mass joins mass to form the heavenly orbs, and orb unites itself to orb to form solar systems which draw towards the source of light, and as they draw towards it commence to revolve owing to their being nearer on one side than on another to some other orb and therefore better able to transfer force on that side than on the other, and thus as they revolve each half of these orbs is alternately illuminated and left dark—or light is divided from darkness, as the Bible story says.

We pass then to the next scene: and now we see the gaseous orbs of the last scene brought so much nearer to the source of light that their masses have differentiated into liquid and gas, owing to the displacement of repulsive force by compulsive force about their particles, and the denser liquid masses have drawn to the different centres—or, according to the Bible story, a firmament divides the waters from the waters.

We pass on to the third scene: and now the orbs have drawn so much nearer to the source of light, and compulsive force has in consequence so far displaced repulsive force about many of the particles, that the different masses in the liquid orbs of the last scene have differentiated into solid and liquid—or, according to the Bible story, the dry land has appeared.

So far the scenes have been just those with which, on a minute scale, we have been familiar in chemistry—in fact, just those summarized in the first part of paragraph 113.

And now we have to turn to the cells for the rest of the story, and in them we find represented another scene, where the view is taken off from the great orbs with their solid land masses and liquid seas and densely clouded skies first to a narrow spot where, from a few albumin and water groups of particles grouped together in a tiny mass, the first living plant cell is evolved, somewhat in the way explained in the last part of paragraph 113—and then a little further on this first plant cell has increased and multiplied and developed into thousands of forms—lichens, mosses, ferns, grasses, weeds, flowering plants and trees—which cover not only all the low-lying land, which being richly charged with salts washed down from the higher ground is fitted to support plant life, but also fill the shallow

waters—or, according to the Bible story, the earth has "brought forth grass and herb yielding seed after his kind, and the tree yielding fruit whose seed was in itself after his kind."

Once more the scene changes: and now we have a representation of the differentiation of the plant form into the animal form, with stomach sac and root-like limbs, somewhat after the manner described in paragraph 114. And we notice that the complete development of the animal forms takes place in water, at a time when heavy torrents fill the shallow lakes and estuaries with masses of bruised vegetable matter carried down from the hills, and thus furnish an abundance of food suitable for assimilation in the stomach sacs of the primitive animals also carried down by the torrents into the estuaries. According to the account in the Bible, the sun and moon become visible just before the first creation of animal forms, thus implying that the sky had become clear, and indicating, as we may assume, that a condensation of heavy clouds previously enveloping the earth and obscuring the sun had taken place, and therefore that the time was one of heavy rain. The Bible story further shows, that the first development of animal forms took place in the water, and that the waters brought forth "abundantly the moving creature that hath life."

And then, in the last scene we have, both in the Bible and in the particles of the nerve cells of the higher animal forms, a representation of the development of the higher animals forms from the lower.

So that if we put away the childish objection that the Bible account implies that each one of the successive acts by which the creature was completed took place in a day of twenty-four hours, we see that the two accounts exactly tally.

127. But besides the story of Creation we may learn something more from the particles; for since we see that repulsive force is almost as necessary to our well-being as compulsive force, it is clear that a fair amount of resistance or opposition is good, and that resistance and opposition only become evil when carried to excess, and when they strive to get absolute sway. But the Bible also tells us that the powers of evil were once angels of God, and that they "kept not their first estate, but left their own habitation," (Jude 6). The particle also tells further, since it is part of a solar system which is, as astronomers tell us, being continually drawn towards one point in the heavens, that though repulsive force most strenuously opposes the action of compulsive force, yet that its resistance is being slowly and steadily overcome, so that one day our earth will become a solid mass, without any liquids—

and "there will be no more sea;" and then all life in its present forms will be impossible—and there will be "a new heavens and a new earth."

128. The cell, besides the creation story, represented on its particles and in its groups, can further tell us that suffering is the order of this life, and that nothing is done without suffering—not always painful suffering, but still suffering. Thus the cell suffers expansion, and, being empty or hungry, takes in the supply of liquid and gaseous particles necessary for the elaboration of material to supply its own wants and the wants of kindred cells. Again, it suffers contraction, and being distended gives up the material required for the growth of its walls, or for the growth or formation of kindred cells. Again, the cell tells of vicarious suffering—of plant cells suffering willingly to supply kindred plant cells; of plant cells suffering unwillingly to supply animal cells in which they have no interest; and of animal cells suffering willingly and unwillingly to supply other animals cells. And therefore we see that the Bible story—that when men had gone over to the side of the Powers of Evil and were alienated from God, it was necessary in order to win men back to life that the Son of God, taking man's form, should suffer as a man for men—is strictly in accordance with other parts of the life story.

129. We find that all through the Bible light is connected with God and God's habitation; and a hot place, a furnace, or a lake of fire, is spoken of as the habitation prepared for the devil and those who side with him. Thus God is spoken of as covering Himself with light as with a garment (Ps. civ. 2); and mention is made of Him as "dwelling in the light which no man can approach unto" (1 Tim. vi. 16); also of a city which "had no need of the sun, neither of the moon, to shine in it: for the glory of God did lighten it, and the Lamb is the light thereof" (Rev. xxi. 23).

And on the other hand, the Bible speaks of a "lake burning with fire and brimstone: which is the second death" (Rev. xxi. 8) and of "an everlasting fire prepared for the devil and his angels" (Matt. xxv. 41). It says that "a day cometh which shall burn as an oven; and all the proud and all that do wickedly shall be stubble: and the day that cometh shall burn them up" (Mal. iv. 1).

Also the Bible says, that "the Son of Man shall send forth His angels, and they shall gather out of His kingdom all things that offend, and them which do iniquity: and shall cast them into a furnace of fire: there shall be wailing and gnashing of teeth. Then shall the righteous shine forth as the sun in the kingdom of their Father" (Matt. xiii. 41—43).

130. The natural life alone has hitherto been re-

ferred to; and no mention has been made, except in paragraph 128, of a higher life. But it is clear that the life of Him, by the operation of Whose will the natural life was originated and is sustained, must be something very different from the natural life itself—must be something far above our comprehension. Though doubtless it is this higher life which is referred to in Genesis ii. 7, as having been breathed into the nostrils of the first man, and doubtless it is the loss of this higher life which constitutes the "second death."

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THE END.

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